Saskatchewan
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STUDY OF HERBICIDES IN SHALLOW GROUNDWATER BENEATH THREE IRRIGATED SITES IN OUTLOOK IRRIGATION DISTRICT, SASKATCHEWAN

- Results of 1987 field investigations -

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H. Maathuis(1), V. Wasiuta(2), W. Nicholaichuk(3) and R. Grover(4)

(1) Saskatchewan Research Council
(2) National Hydrology Research Institute, Groundwater Division
(3) National Hydrology Research Institute, Surface Water Division
(4) Agriculture Canada, Regina Research Station

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1. INTRODUCTION

Potential migration of agricultural chemicals from the land surface, though the unsaturated zone, into the saturated zone is increasingly becoming an environmental and public health concern (e.g., Garner, 1986; Holden, 1986).

In Canada, only a few groundwater related pesticide and herbicide studies have been documented. Krawchuk and Webster (1984, 1987a,b) investigated the occurrence of herbicides in shallow groundwater beneath an irrigated site in Manitoba and found detectable levels of chlorothalonil, carbofuran and 2,4-D. Priddle et al (1987) documented the persistence of aldicarb in groundwater of the fractured sandstone aquifer of Prince Edward Island. Frank et al (1979) and the Ontario Ministry of the Environment (1985) published data on private and municipal wells in Ontario which, at least temporarily, were contaminated by herbicides.

While large amounts of herbicides are used in Saskatchewan for agricultural purposes (Table 1), very few studies have been carried out to investigate whether or not the quality of shallow groundwater is affected by these chemicals. Maathuis (1987) investigated the possible occurrence of pesticides and herbicides in groundwater of a surficial aquifer near Nokomis. No evidence was found of contamination of the groundwater by the herbicide 2,4-D, used at the site in the past few years. Smith et al (1988) found detectable levels of picloram in shallow groundwater at the Primrose Lake Air Weapons Range, in north-western Saskatchewan. However, it should be noted that the Weapons Range is located well north of the arable zone in Saskatchewan.

Table 1. HERBICIDES USED AGRICULTURALLY IN SASKATCHEWAN
(active ingredient X 1000 kg)
(Source: Manitoba Agriculture, Economics Branch, Agriculture Statistics)

Year	2,4 - D TOTAL	MCPA TOTAL	TCA	DALAPON	OTHERS (1)	WILD OAT (2)
1980	1629	457	219	4	341	NR
1981	2318	644	149	26	773	NR
1982	2150	531	112	3	1670	NR
1983	1940	632	127	37	1801	3688
1984	2092	535	127	37	1545	3565
1985	2117	492	63	122	990	3369
1986	2670	550	161	NR	1247	3837
1987	2335	671	140	NR	1192	1801

(1) Bromoxynil, Diacamba, Dichloroprop, Roundup, Stampede, etc.

(2) Asulox, Atrazine, Avadex, Hoe-grass, Poast, Treflan, etc.

NR means not reported.

The present study describes the results of the 1987 study to determine whether or not herbicides occur in shallow groundwater beneath three irrigated sites in the Outlook Irrigation District, Saskatchewan. The study was carried out in joint cooperation between the National Hydrology Research Institute, the Saskatchewan Research Council, and Agriculture Canada, Regina Research Station.

2. STUDY OBJECTIVES

The objectives of the study are to:

- determine whether or not herbicides applied on the land surface of selected irrigated sites migrate downward through the unsaturated zone into the saturated zone.
- determine the persistence of herbicides in the saturated zone.
- determine the factors which control the downward leaching of herbicides.
- determine whether or not the results of the studies can be used in mass transport models to predict the behavior of various agricultural chemicals under similar and/or different subsurface conditions.

Background data on the concentrations of herbicides in shallow groundwater in the Outlook area do not exist. Consequently, the 1987 study was of a reconnaissance type, aimed at establishing whether or not the quality of shallow groundwater was affected by downward migration of herbicides. The absence or presence of herbicides in the groundwater then would aid in defining more detailed studies at one of the selected sites.

3. SITE SELECTION

The following criteria were applied in selecting sites within the Outlook Irrigation District for detailed study:

- either the geological and hydrogeological setting of a site had to be known or the landowner would permit testhole drilling to establish the setting.
- shallow piezometers were either available for sampling or could be constructed at the site.
- data on land use, type of agricultural chemicals applied, application rate and irrigation could be obtained.

Based on the criteria above, the following three sites were selected:

- Pederson site (LSD16-17-28-07-W3)
- Saskatchewan Irrigation Development Centre (SIDC) (SW-15-29-08-W3 and LSD02-15-29-08-W3)
- Konst site (Sections 1,2,3, southern halves Sections 10,11, and 12, Township 30, Range 8, W3)

The location of these sites is shown in Figure 1. The sites are discussed in detail in the following sections.

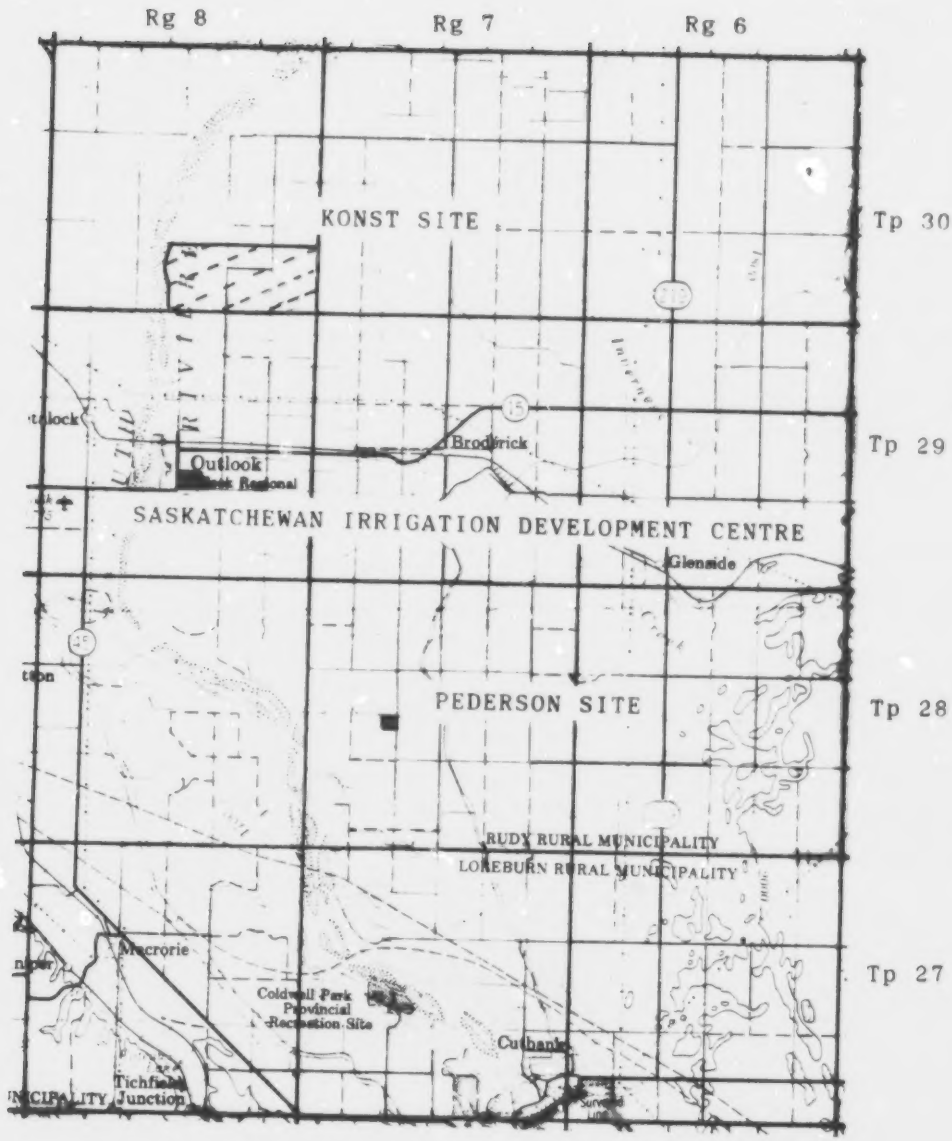

FIGURE 1 LOCATION OF STUDY SITES.

4. BACKGROUND INFORMATION

Christiansen (1984,1987) studied the local geology, groundwater resources and history of deglaciation in the Outlook area. The geology and groundwater resources on a regional scale were shown by Christiansen and Meneley (1971). The surficial geology was investigated by Scott (1971), and a surficial geology map was prepared by the Saskatchewan Research Council (1986). Soils in the area were described by Ellis et al (1968). Climatological data for Outlook are provided by Bergsteinsson (1976).

5. PEDERSON SITE

5.1 Introduction

The Pederson site (Figure 1) is located at LSD 16-17-28-07-W3 and covers an area of 16.7 ha. The topography at the site shows a gentle slope of 1%, in a westward direction. The site, irrigated by the corrugation-flooding method, divided into 6 strips, requires between 3 and 5 days to irrigate. The research site has been flood-irrigated since 1980, the field immediately to the west since 1978.

Since 1986,the site has been used to carry out research on herbicide, nutrient and water drainage from a flood irrigated field (Nicholaichuk et al, 1987, 1988). Analysis of water samples from a shallow piezometer, constructed at the site in 1986, showed detectable concentrations of dicamba and MCPA (Nicholaichuk et al, 1987). Consequently, the Pederson site was selected for a detailed groundwater pesticide study. The groundwater study, combined with the on-going surface water investigation, provides an opportunity to determine in detail the fate of herbicides applied to a flood irrigated field. Within the Outlook Irrigation District central pivot or wheel line irrigation systems are commonly used and flood irrigation is applied to only a small percentage of the land irrigated (Water Resource Consultants Ltd., 1986). However, selection of the Pederson site is justified since flood irrigation probably represent the worst case scenario in terms of propensity for downward movement of herbicides.

The groundwater study at the Pederson site included: establishing the geological setting, installing piezometers,sampling water for herbicide, major ion and stable isotope analyses, and monitoring water

levels. All the data collected for the site are presented in a separate appendix accompanying this report (Maathuis, 1988). An overview of the activities relevant to the groundwater study is provided in Table 2.

5.2 Geology

From a regional perspective, the geology at the Pederson site includes, in ascending order: Lea Park Formation, Judith River Formation, Bearpaw Formation, Empress Group and Sutherland and Saskatoon Groups (Christiansen, 1987, cross section G - G'). The geological setting is illustrated schematically in Figure 2.

To establish the near-surface geology and lithology in more detail, two testholes were augered to a depth of 18.3 m below ground surface. Additional geological information was obtained from the augerholes drilled for installation of piezometers. The location of the testholes and piezometer holes is shown in Figure 3. The lithology was described using air-dried auger samples, typically collected at 0.6 metre intervals. Selected samples were analysed for grain size distribution, %wt organic carbon and carbonate content. Augerhole logs and results of the analyses carried out on the selected samples are presented by Maathuis (1988). The near-surface geology at the Pederson site is shown in Figure 4 and is briefly discussed below:

- The Surficial Stratified Drift, up to 6 metres thick but typically between 2 and 4 metres thick, consists of oxidized silts and clays. Grain size analyses indicate that these sediments can be classified as a silty clay or as a clay loam.

TABLE 2 SUMMARY OF 1987 ACTIVITIES AT PEDERSON SITE

May 01	- Area fertilized with anhydrous ammonia at rate of 147 kg/ha as N.
May 11	- Area seeded to soft white spring wheat. Fertilizer applied: 5.6 kg/ha N and 28 kg/ha P.
May 20 - 22	- Piezometers installed. Piezometers No. 6 and 10 sampled for major ion analysis.
June 01	- Date of crop emergence.
June 07	- Crop sprayed with Hoegrass (Diclofop-methyl) at recommended rate. Activity: 284 gram active ingredient/litre. Total active ingredient applied: 12,568 grams.
June 09	- 0.46 km of supply canal sprayed with Roundup (glyphosate: 359 gr/l)
June 10 - 11	- Piezometers sampled for herbicide and major ion analyses.
June 17	- Crop sprayed with Dyvel (Dicamba and MCPA 1:4) Total Dicamba applied: 1,754 grams Total MCPA applied: 7,014 grams
June 23 - 26	First irrigation event: 24,331 m3 applied to area, 2896 m3 runoff.
June 23-July 6	- Water supply canal filled.
June 24	- Sampled irrigation water for major ion analysis.
June 26	- Sampled SIDC and piezometer No. 3 for major ion analysis.
July 06 - 07	- Sampled piezometers for herbicide analyses.
July 16 - 17	- Sampled piezometers for herbicide analyses.
Aug. 03 - 13	- Water supply canal filled.
Aug. 05 - 07	- Second irrigation event: 18,348 m3 applied, runoff 1619 m3.
Aug. 05 -06	- Sampled Pederson farm wells for major ion and pesticide analyses.
Aug. 25 - 26	- Sampled piezometers for herbicide analyses. Selected samples taken for major ion and stable isotope analyses.
Sept. 30	- Sampled piezometers 03, 05, 06, 08, 12 and 13 for herbicide analyses.

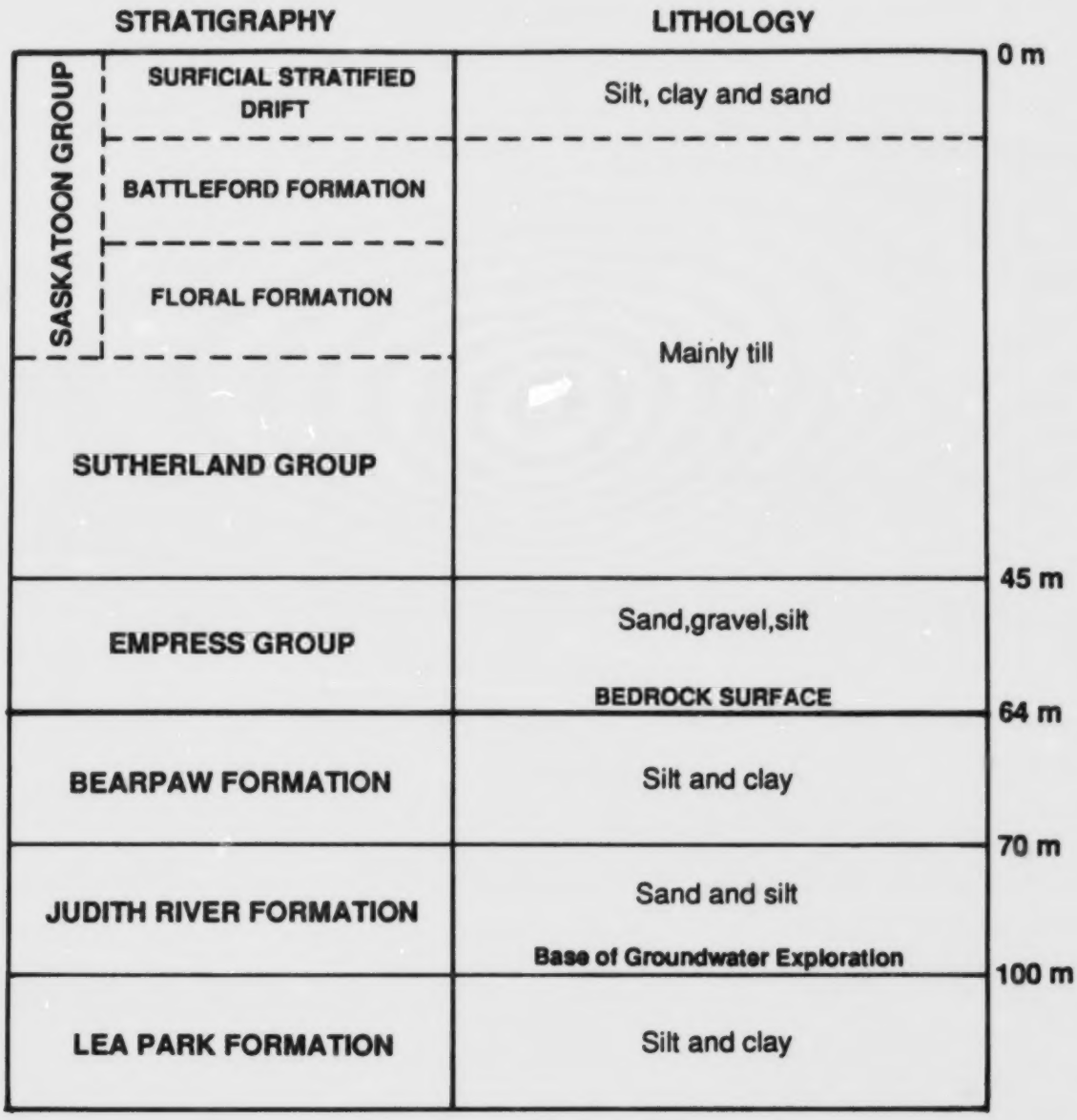

Figure 2 Schematic illustration of stratigraphy and lithology beneath Pederson Site (Depth below ground surface approximate only)

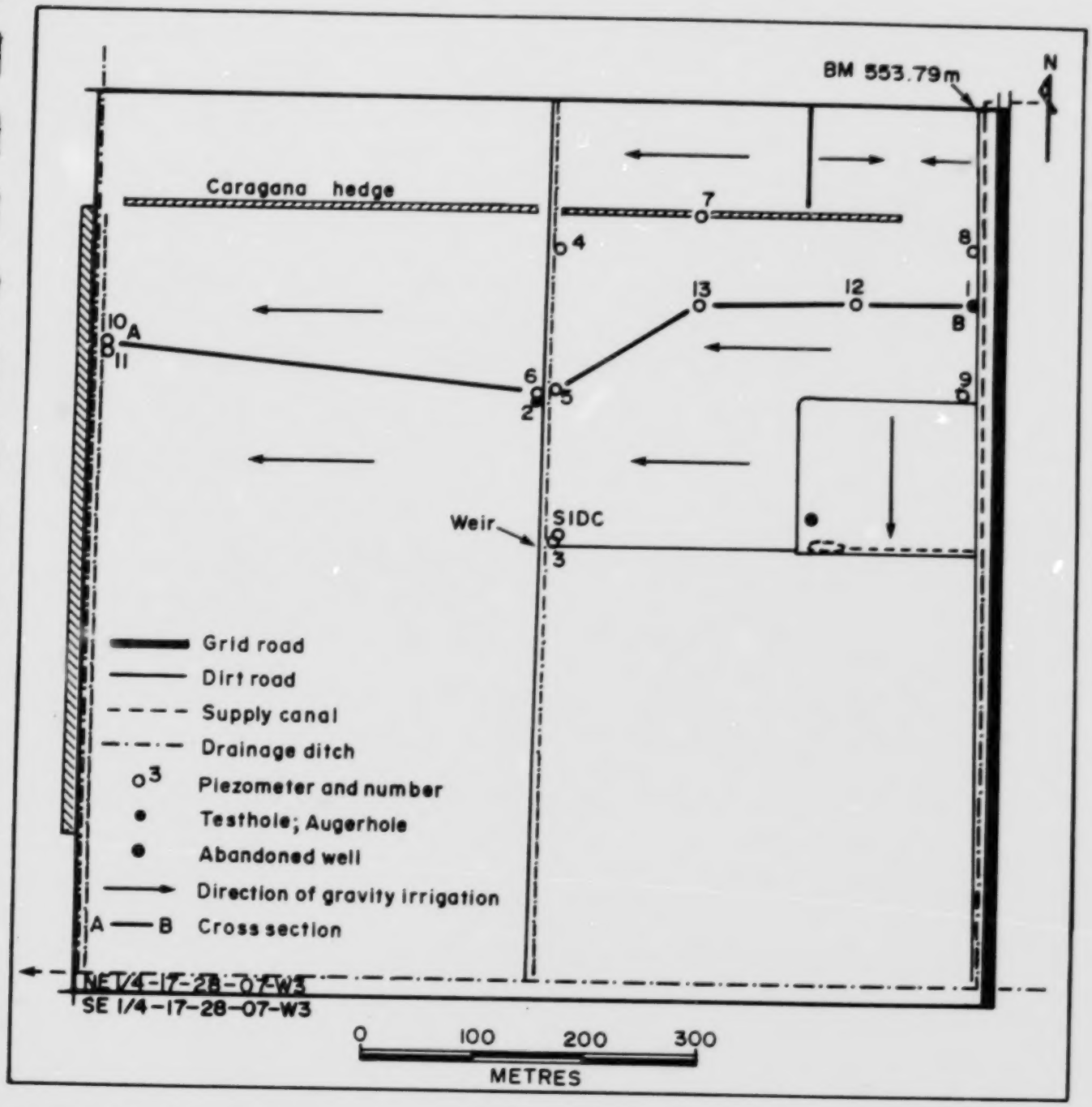

Figure 3 Location of testholes and piezometers at Pederson site

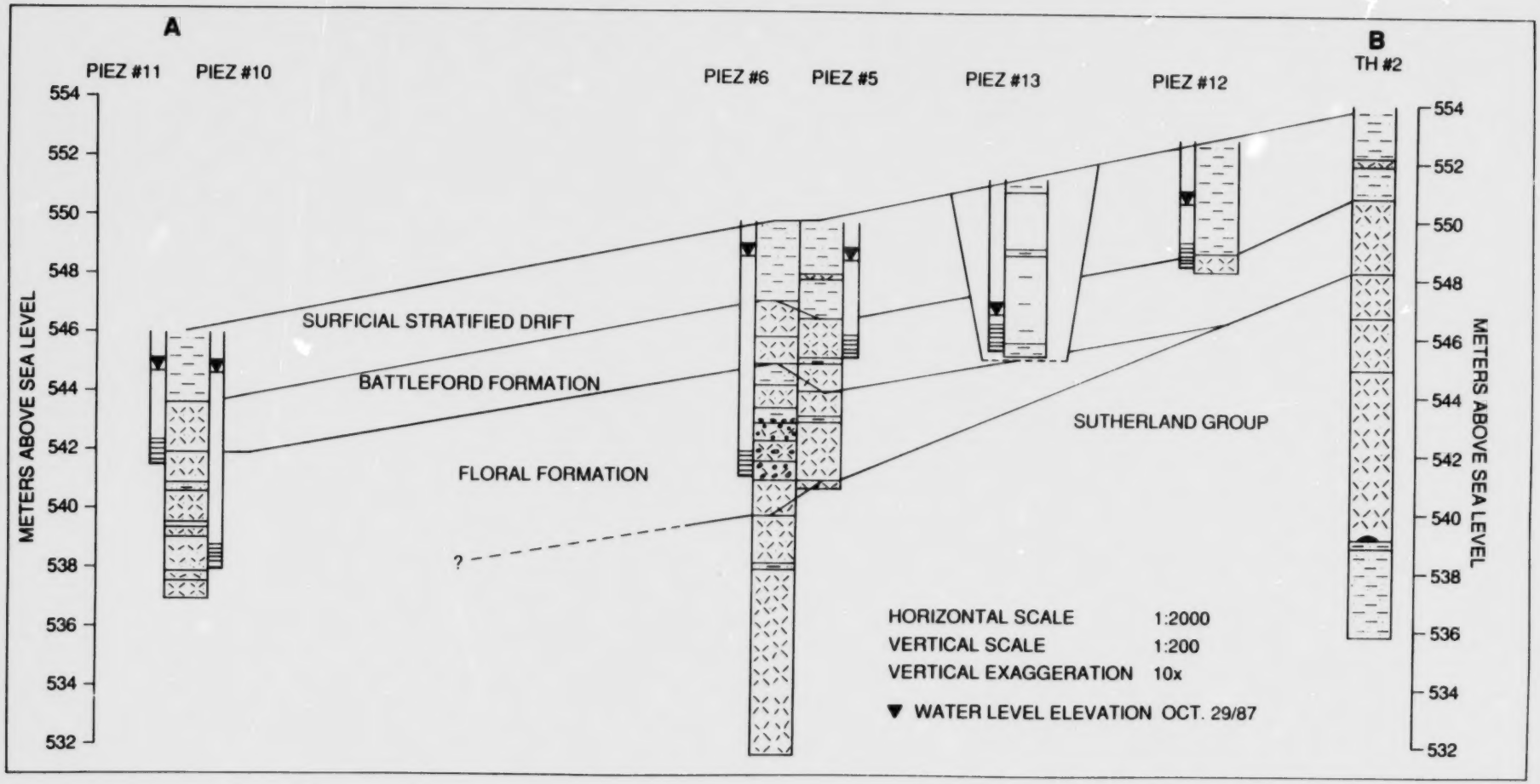

Figure 4 Cross section at Pederson site

The sands encountered in hole No. 13 (see Figure 4) have been interpreted as a channel fill. The lateral extent of this channel has not been determined and would require drilling of additional augerholes. The sediments of the Surficial Stratified Drift were deposited in a glacio-lacustrine environment during the final deglaciation of the area.

- The Battleford Formation, up to 3 metres thick, is composed of oxidized, unstained, soft till. It should be noted that the contact between the Battleford Formation and the overlying Surficial Stratified Drift is gradational. The contact can not always be uniquely defined.

- The Floral Formation consist of sandy, pebbly, till which is oxidized and fractured. In holes No. 6, 7 and 10, some sand, silt and gravel layers occur within this Formation. There is insufficient information to determine whether or not these stratified deposits are continuous.

- The Sutherland Group consists of hard, dense, till and the upper part is weathered. The weathering zone is olive in color and contains joints with yellowish - brown staining and gypsum crystals. Christiansen (1984) subdivided the Sutherland Group into a Lower, Middle and Upper unit. However, there is not sufficient information to subdivide the Sutherland group beneath the Pederson site.

5.3 Soil

The Pederson site is located in the Dark Brown soil zone. The soil at the research site is of the Elstow Association, described by Ellis et al (1968).

5.4 EM-31 survey

On May 4, 1988, the variation and distribution of the apparent electrical ground conductivity was determined using a Geonics EM-31 instrument. This instrument has an intercoil spacing of 3.7 metres, which yields an effective depth of exploration of about 6 metres (McNeill, 1980).To facilitate mapping of the apparent electrical ground conductivity a network of survey lines was set up, with the eastern edge of the field as baseline. At 25 m intervals along the baseline a 400 m long survey line was established which ran perpendicular to the baseline. Along each of these survey lines measurements were made at 5 m intervals.

The observed values for apparent electrical ground conductivity ranged from less than 30 mmhos/m to 90 mmhos/m. The distribution of the apparent electrical conductivity is shown in Figure 5. The contours shown in this figure were generated using a computer contouring program and a selected contour interval of 10 mmhos/m.

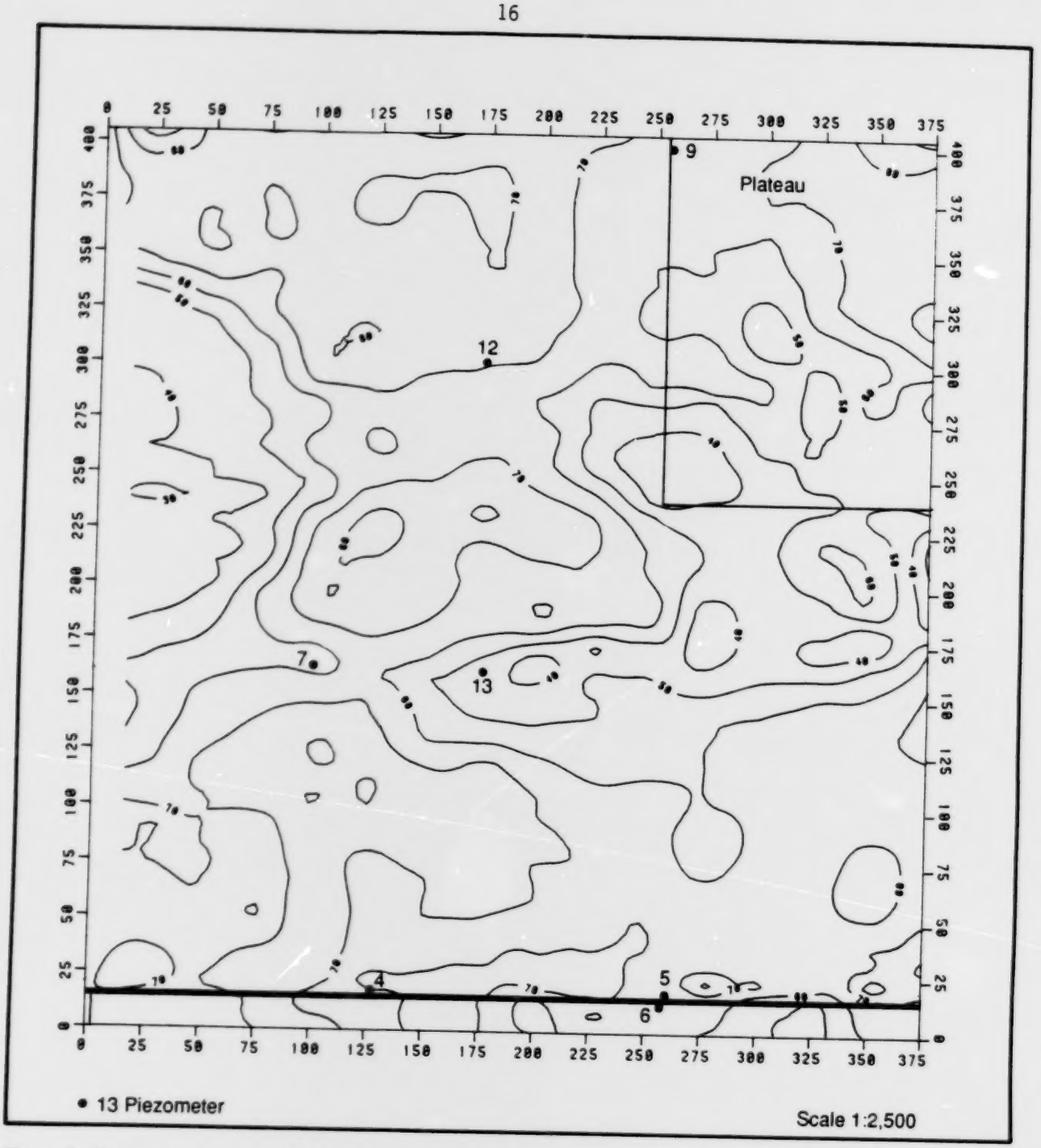

Figure 5 Distribution of apparent electrical ground conductivity at Pederson site (contour interval 10 mmhos/m).

An quantitative interpretation of the data is not possible but qualitatively the data indicate the following:

- values of less than 50 mmhos/m likely indicate the presence of sands at shallow depth below ground surface. For example, in the vicinity of piezometer No.13 the apparent electrical ground conductivity is less than 50 mmhos/m and the augerhole log for this piezometer indicates sand at a depth of less than 1 metre below ground surface. Because of the presence of a topographical ridge, the low values observed north of the caragana hedge may either indicate sand at shallow depth or dryness of the shallow subsurface.

- values greater than 50 mmhos/m represent the clay and water content of the silts and clays of the Surficial Stratified Drift and the distribution of salts within the shallow subsurface. It is interesting to note that, for example, the augerhole log for piezometer No. 9 indicates the presence of gypsum at a depth interval of 1 to 3 metres below ground surface. The presence of gypsum can be interpreted as evidence of very little net downward flow (Keller and van der Kamp, 1988).

5.5 Piezometer Installations

In addition to the existing piezometer, referred to as SIDC piezometer,nine piezometers were constructed at the research site itself, and two piezometers were located at the border of the adjacent field, situated down slope of the research site. The location of the piezometers is shown in Figure 3.

At the time of construction of the piezometers, no information was available as to the depth to the water table, and the nature and magnitude of the water table fluctuations. Since it was imperative that the piezometers would be completed at the shallowest depth possible, augerholes were typically drilled to a depth at which the soil was considered to moist enough to yield water to a piezometer. Most of the piezometers were completed at a depth of 4 to 6 metres below ground surface, either in the Surficial Stratified Drift or in the underlying Battleford Formation.

An exception are piezometers 6, and 10 which were completed in Floral sands and gravels, at a depth of 8 to 9 metres below ground surface. Piezometer No. 7, completed at a depth of 6.9 metres below ground, is believed to be completed in a Floral sand and silt layer.

A piezometer assembly typically consists of a 50 mm diameter, 750 mm long, slot # 10, stainless steel screen and 50 mm diameter, schedule 80, PVC casing. Piezometers were installed in dry holes, with the exception of piezometers No. 6, 10 and 11. Piezometers No. 6 and 11 contained some water at the time of gravel packing. Piezometer No. 10 had to be washed in and could not be gravel packed. All other piezometers have been gravel packed around and above the screen section with

12 - 20 frac sand. The length of the gravel packs is in the 1 to 2 metre range. About 4.5 L of bentonite pellets were placed on top of the gravel pack and the remainder of the annulus was backfilled with a 3:1 sand/-bentonite powder mixture. The top 0.5 metres was backfilled with auger cuttings, mixed with bentonite powder. Piezometer construction and completion details are presented together with the augerhole logs (Maathuis, 1988). The depth of the piezometers and the stratigraphy of the completion zones are provided in Table 3.

5.6 Water Level Observations

During the period June - September, the water level in the piezometers was measured every 7 to 10 days. Frequent daily water level observations were made during the irrigation events. A Keck - Stevens recorder system was installed on piezometer No. 3 to obtain a continuous water level record for the entire crop season. Collection of water level data continued throughout the fall and winter of 1987, at a frequency of one or two measurements per month. Maathuis (1988) provides a listing of water level data, water level plots and records obtained from the water level recorder.

TABLE 3 DEPTH AND STRATIGRAPHY OF COMPLETION ZONE OF PIEZOMETERS AT PEDERSON SITE

PIEZOMETER NAME	BOTTOM PIEZ. BELOW GROUND SURFACE (M)	STRATIGRAPHY OF COMPLETION ZONE
SIDC	3.90	Stratigraphy not known
No. 03	4.21	Surfical Stratified Drift/ Battleford Formation
No. 04	4.21	Surficial Stratified Drift
No. 05	4.73	Surficial Stratified Drift/ Battleford Formation
No. 06	8.73	Floral Formation
No. 07	6.54	Floral Formation
No. 08	5.94	Surficial Stratified Drift/ Battleford Formation
No. 09	5.54	Surficial Stratified Drift
No. 10	8.14	Floral Formation
No. 11	4.61	Surficial Stratified Drift/ Battleford Formation
No. 12	4.37	Surficial Stratified Drift
No. 13	5.87	Surficial Stratified Drift

5.6.1 Groundwater Flow Regime

A typical distribution of the hydraulic head, represented by the water level data for late October 1987, is shown in Figure 6. Because of the complex geological setting and the small number of piezometers within this setting, contouring of the data can not be justified. However, the data suggest a westerly to northwesterly flow within the shallow groundwater flow system.

The data also indicate that the sands at piezometer sites No. 13 and 7 may have a significant impact on the shallow groundwater flow. Whether or not the sands of the Surficial Stratified Drift at site No. 13 and the Floral sands at site No. 7 are hydraulically connected has not been established.

Data from the Saskatchewan Archives Board show that a 64 m deep, abandoned,well at the site had a reported water level of 18 metres below ground surface in 1935. This well presumably was completed in the Empress Group (Christiansen, 1987, cross section G - G'). The water level in this well suggest that there is a vertical downward gradient, but the amount of downward flow probably is not more than a few centimetres per year.

The shallow groundwater regime at the site is probably mainly controlled by input from snowmelt and irrigation and output by evapotranspiration. The lateral and vertical flow components of this system are probably small.

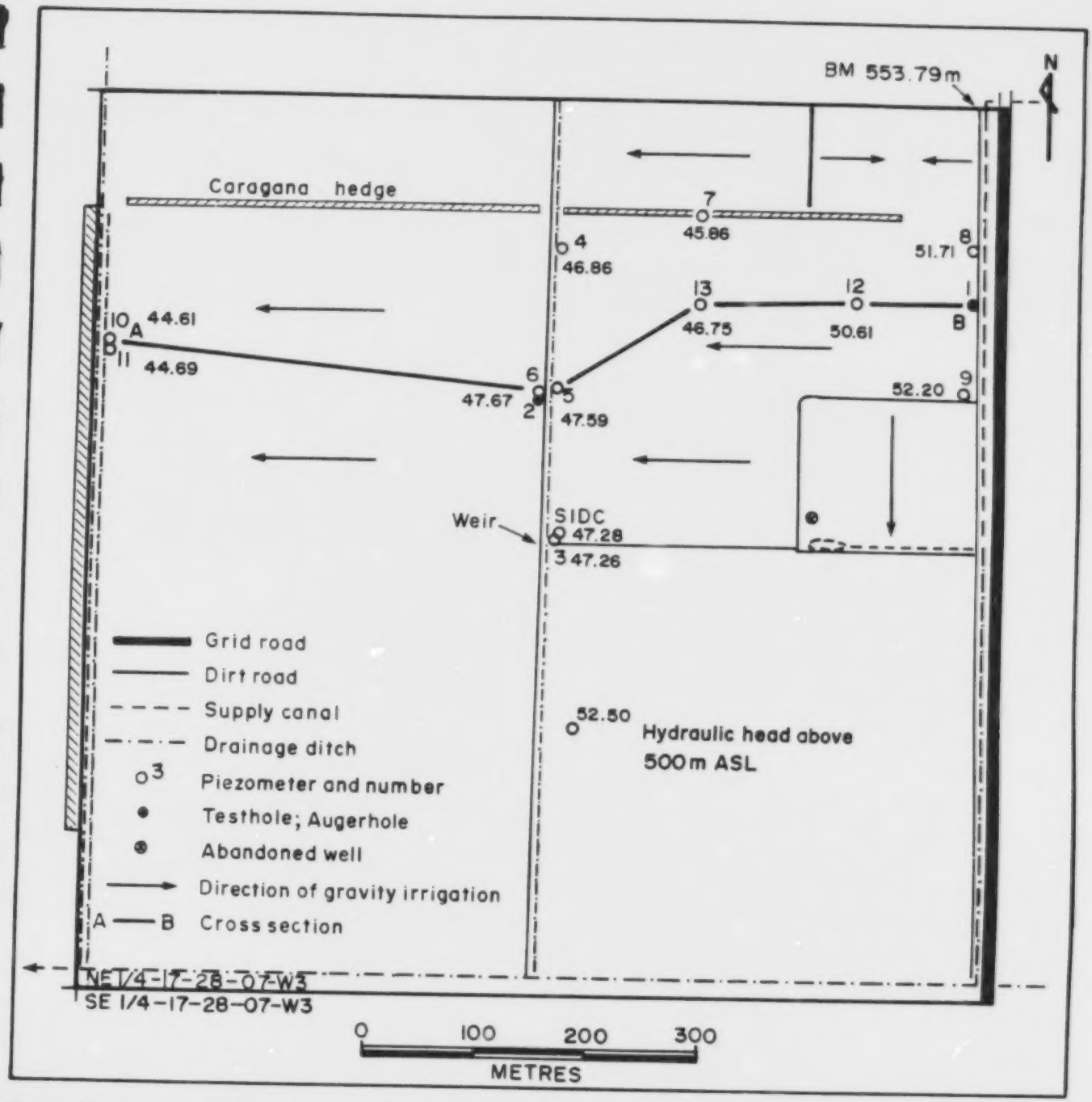

Figure No. 6 Distribution of hydraulic head data at Pederson site

5.6.2 Hydrograph Interpretation

Inspection of the hydrographs, Appendix A of this report, show that the hydrographs can be categorized into two groups, each group showing a distinctly different water level behavior.

The water level in all piezometers, except in piezometers No. 13 and 7, show a rapid and pronounced response to irrigation events. The observed significant increase in the water level elevation during irrigation events is probably due to a capillary fringe effect. The sediments of the Surficial Stratified drift and Battleford Formation are silty and clayey in nature and consequently, it is expected that the tension saturated zone (capillary fringe) is relatively thick. During irrigation events the upper portion of the soil will become saturated and a strong vertical gradient is temporarily created. Water which moves downward and reaches the tension saturated zone causes a change from tension-saturated to saturation under positive pressure. Because of the expected thickness of the tension-saturated zone, only a small amount of water would be needed to cause the observed significant rise in the water level. Water level data suggest that the time between the moment that irrigation water reaches a piezometer site and the first indication of a water level rise is typically less than a day and might only be several hours. Although response times have not been determined, it will take a finite time before head changes in the material opposite the gravel packs are fully registered as similar water level changes in piezometers. Consequently, the rapid response of the water level in piezometers after irrigation water has reached the site implies a very rapid downward movement of at least a small amount of water. For such

a rapid downward movement to occur, the hydraulic conductivity would have to be relatively high. The decline of the water level after irrigation events is probably mainly due to evapotranspiration. After the onset of the frost season, in early November,the rate of decline decreases and the observed decline is probably controlled by downward and perhaps some lateral flow. It is interesting to note that the water level in the piezometers dropped significantly during January and February of 1988. This drop coincides with a period of extreme cold and the drop might be related to upward movement of water from the saturated zone to the freezing front in the soil (Gray and Granger, 1986). The increase in the elevation of the water level in March 1988 is likely due to recharge, derived from snowmelt, through the frozen ground. It is unlikely that the observed water level increase can be attributed to melting of frozen water in the soil.

The hydrographs for piezometers No. 7 and 13 (Appendix A) show a significantly different water level behavior. These piezometers were completed in a Floral sand and in a channel sand within the Surficial Stratified Drift, respectively. The response of the water levels in these piezometers to the first irrigation event is delayed and much less pronounced. Since the water level in these piezometers is between 5 and 6 metres below ground surface, the lack of response is probably due to a thicker and drier unsaturated zone and a thinner tension-saturated zone. The magnitude of the response also may have been affected by a difference in the storage coefficient between the silts and clays, and sands. A change in moisture conditions as result of the first irrigation event, coupled with an increase in lateral flow from the silts and clays

into the sands, probably explains the more pronounced response to the second irrigation event. After the second irrigation event, the water level changes in the piezometers probably are controlled by lateral inflow from the silts and clays, by lateral flow within the sands, and by downward flow.

5.7 Water Quality

Shortly after the piezometers were constructed, narrow diameter Teflon tubing was installed in each piezometer to reduce chances of cross contamination during sampling. Representative water samples were obtained by pumping the piezometers dry and allowing the water level to recover for a period of up to 24 hours. A peristaltic pump was used to pump the piezometers dry and for collection of water samples. Piezometers No. 6 and 10 could be pumped on a sustained basis with the peristaltic pump. Before water samples were collected from these piezometers, several piezometer volumes of water were removed.

Water samples for major ion analyses were filtered in the field using Millipore filtering equipment and 0.45 micron filters. For herbicide analyses about 0.5 to 0.75 L of unfiltered water was collected in 1 L glass bottles. Prior to usage, the glass bottles were washed with a detergent and distilled water. After rinsing with pesticide grade acetone and hexane, the bottles were baked overnight in a drying oven at a temperature of 350 C. Tin foil, rinsed with hexane and also baked in the oven, was placed over the opening of the bottles and the bottles were closed with Teflon lined caps. Samples for herbicide analyses were kept in coolers with ice-packs and within a 24 hour period were frozen

at a temperature of -20 C. The samples were kept frozen until analysed. The analytical methods used to determine the herbicide concentrations in the water samples have been described by Cessna et al (1985).

5.7.1 Major Ion Analyses

The results of the chemical analyses for major ions are shown in Table 4 and Figure 7. Water from the piezometers is typically of the calcium/magnesium - sulphate type and the sum of ions may range from 4230 to 8630 mg/L. In contrast, irrigation water is of the calcium/-magnesium - bicarbonate type with a sum of ions of 320 mg/L.

The water quality data for the piezometers show that both the sum of ions and concentration of individual constituents varies laterally. For example, the nitrate concentration may vary from 0.28 to 132 mg/L NO3-N and the dissolved organic carbon concentration ranges from 16 to 302 mg/L. The relatively high concentration of dissolved organic carbon, assumed to be due to humic acids, probably is the reason for the yellowish color of the water. The lateral variation in water quality is probably due to the heterogeneity of the shallow subsurface, the distribution of recharge within the study area, and the spatial variation of the geochemical processes in the unsaturated zone. The mineralized nature of the shallow groundwater at the site can be considered an indication of a poorly flushed system.

TABLE 4 MAJOR ION DATA FOR WATER FROM PEDERSON PIEZOMETERS AND PEDERSON FARM WELLS, AND FOR IRRIGATION WATER.

PIEZ. NAME	DEPTH M	DATE DDMMYR	pH LAB	CA MG/L	CA (HCL) MG/L	MG MG/L	NA MG/L	K MG/L	FE MG/L	MN MG/L	HCO3 MG/L	SO4 MG/L	CL MG/L	NH4-N MG/L	NO3-N MG/L	KJELD. -N MG/L	TOT. -N MG/L	PO4-P MG/L	TOT. P MG/L	TOT. C MG/L	TOT. INORG. MG/L	TOT. ORG. C MG/L	SUM IONS MG/L	COND. MG/L	T.H. CACO3 MG/L	T.A CACO3 MG/L	ERROR BAL %
SIDC	4.15	100687	7.91	386	395	866	1210	16	0.25	0.19	729	6420	59	0.30	4.5	3.4	7.9	<0.01	0.03	242	119	123	9707	8800	4520	598	1.39
SIDC	4.15	260687	7.52	463	455	839	898	12	0.06	<0.01	1120	5530	13	0.24	0.25	2.7	3	<0.01	0.05	280	180	100	8876	7890	4600	918	0.90
SIDC	4.15	280887	7.77	460	450	650	654	10	0.07	<0.01	1190	4140	18	0.05	4.4	N/D	N/D	0.01	N/D	278	176	102	7142	6350	3822	978	0.66
PED 03	4.49	260687	7.67	442	404	840	840	11	0.14	0.02	1120	5370	5.7	0.31	0.84	1.7	2.5	0.01	0.03	240	180	60	8633	7660	4550	918	0.93
PED 04	4.42	110687	7.99	489	N/D	279	292	12	N/D	N/D	580	2610	20	N/D	N/D	N/D	N/D	N/D	N/D	N/D	N/D	N/D	4282	4000	2360	475	3.25
PED 05	5.05	110687	7.81	429	N/D	384	918	21	N/D	N/D	424	4110	98	0.11	8.8	4	13	<0.01	0.10	175	81	94	6423	6470	2650	348	1.29
PED 06	9.00	220587	7.35	532	532	253	420	19	0.09	0.02	257	2790	129	N/D	23	N/D	N/D	0.01	N/D	117	55	62	4502	4580	2360	211	1.10
PED 06	9.00	100687	7.77	519	519	258	446	19	<0.01	0.03	272	2790	121	0.06	21	0.44	21	<0.01	0.03	119	49	70	4518	4650	2350	223	0.33
PED 07	6.93	110687	7.82	523	523	292	660	20	<0.01	0.08	404	3230	186	0.08	22	0.75	23	<0.01	0.74	189	74	115	5413	5580	2500	331	0.84
PED 08	6.13	110687	8.32	429	420	335	1320	22	0.14	0.11	502	4680	57	0.11	9.2	0.68	9.9	<0.01	0.16	189	93	96	7386	7500	2440	411	0.46
PED 08	6.13	260887	7.79	407	427	368	1150	18	0.03	<0.01	423	4600	49	0.08	7.3	N/D	N/D	<0.01	N/D	202	82	120	7047	6910	2530	347	1.72
PED 09	5.85	110687	7.75	532	528	346	1180	27	<0.01	0.05	679	3280	454	0.09	132	0.18	132	0.01	0.07	421	119	302	7082	7720	2750	556	2.58
PED 09	5.85	260887	7.50	496	495	372	1220	24	0.03	0.03	593	3970	330	0.07	113	N/D	N/D	<0.01	N/D	357	98	259	7505	7470	2770	486	0.33
PED 10	8.38	220587	7.26	481	472	249	404	19	0.04	0.03	331	2710	44	N/D	3	N/D	N/D	0.03	N/D	94	74	20	4251	4290	2220	271	0.60
PED 10	8.38	100687	7.73	459	472	248	391	22	<0.01	0.03	353	2590	48	0.05	3.7	0.12	3.8	<0.01	0.02	87	71	16	4127	4220	2160	289	0.37
PED 11	4.87	100687	7.98	408	416	559	413	14	<0.01	0.02	532	3710	14	0.06	0.28	0.56	0.84	<0.01	0.03	128	106	22	5651	5330	3310	436	1.00
PED 12	4.61	260887	7.58	552	558	314	708	11	0.11	0.03	845	3200	179	0.07	14	N/D	N/D	<0.01	N/D	369	132	237	5871	5710	2660	693	1.21
PED 13	6.18	100687	8.03	747	661	339	703	23	<0.01	0.04	562	4360	92	0.07	4.3	3.6	7.9	<0.01	0.04	180	111	69	6845	6200	3250	461	3.29
PED 13	6.18	260887	7.60	624	624	434	570	23	0.03	<0.01	532	3960	85	0.05	6.6	N/D	N/D	<0.01	N/D	192	86	106	6257	5830	3340	436	0.97
CANAL*		240687	8.66	45	45	17	19	2.1	<0.01	0.01	169	65	5	0.14	0.11	0.14	0.25	0.01	0.06	36	32	4	323	406	182	146	1.32
PIPE		240687	8.07	45	45	18	19	2.2	0.01	<0.01	179	64	4.9	0.24	0.16	0.24	0.4	<0.01	0.02	40	33	7	333	409	183	147	2.42
PED NEW	5.50	50887	7.96	493	493	251	390	17	0.04	0.82	404	2520	71	N/D	14.2	N/D	N/D	N/D	N/D	N/D	N/D	N/D	4210	4140	2260	331	1.05
PED OLD	8.50	60687	7.86	408	417	239	344	14	0.29	0.94	427	2270	24	N/D	0.22	N/D	N/D	N/D	N/D	N/D	N/D	N/D	3728	3730	2000	350	0.34

NOTES: * IRRIGATION WATER SUPPLY CANAL
IN CALCULATING SUM OF IONS NO3-N WAS CONVERTED TO NO3-NO3
N/D MEANS NOT DETERMINED
PED NEW, OLD: PEDERSON FARM WELLS
ANALYSES BY SASKATCHEWAN RESEARCH COUNCIL

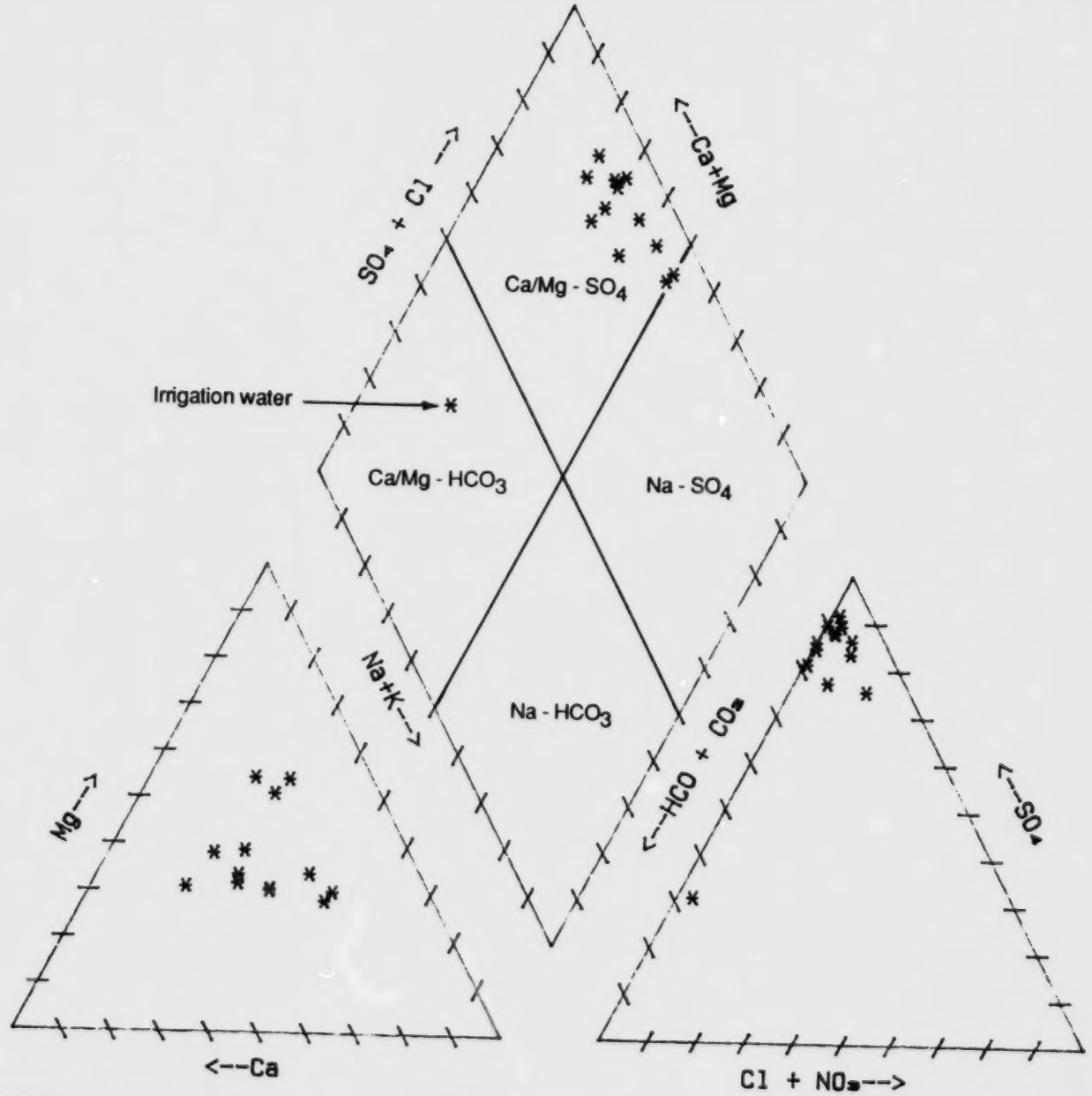

FIGURE 7 PIPER-PLOT OF WATER QUALITY DATA FOR PEDERSON PIEZOMETERS AND FOR IRRIGATION WATER

5.7.2 Isotope Analyses

Samples taken on August 25-26, 1987, were analysed for tritium, oxygen-18 and deuterium (Table 5). The enriched tritium data indicate that the water,or at least a large fraction of the water, in most of the piezometers has entered the groundwater after 1953. The low tritium concentration in water from piezometer No. 9 indicates that this water to a large degree must have originated prior to 1953. The delta-O18 and delta-H2 concentrations in water from the piezometers shows large variations and a distribution pattern which are difficult to explain. The data probably indicates mixing of waters with different oxygen and deuterium concentrations.

5.7.3 Herbicide Analyses

In 1987 the herbicides Dyvel (diacamba and MCPA 1:4) and Hoegrass were applied on the land and consequently, groundwater samples from selected sampling events were analysed for dicamba, MCPA and diclofop-methyl. The results of the analyses are listed in Table 6 and are discussed in the following sections.

It should be noted that the fields adjacent to the research site were sprayed in the fall of 1986 with Banvel (dicamba) and 2,4-D. The research site was not treated with these herbicides but Roundup (glyphosate) was applied to certain spots. In the fall of 1987 no herbicides were applied to the research site or adjacent fields.

TABLE 5 STABLE ISOTOPE DATA FOR WATER FROM PEDERSON PIEZOMETERS AND FOR IRRIGATION WATER.

PIEZOMETER NAME	ENRICHED TRITIUM* (TU)	DELTA-O18** O/OO SMOW	DELTA-H2** O/OO SMOW
SIDC	ND	-16.4	-127
NO. 3	ND	ND	ND
NO. 4	ND	-16.9	-139
NO. 5	56.3 +- 3.8	-16.0	-115
NO. 6	46.7 +- 3.2	-16.6	-131
NO. 7	46.3 +- 3.2	-21.2	-161
NO. 8	61.4 +- 3.6	-18.2	-136
NO. 9	3.6 +- 0.7	-17.7	-114
NO. 10	ND	-18.8	-131
NO. 11	ND	-18.8	-154
NO. 12	52.2 +- 3.5	-16.7	-129
NO. 13	65.5 +- 4.4 66.8 +- 4.5	-15.8	-132
SUPPLY CANAL	ND	-15.6	-118

NOTES: * Analysis by Evironmental Isotope Laboratory, University of Waterloo.
** Analysis by Department of Geological Sciences, University of Saskatchewan.
ND means not determined.

TABLE 6 RESULTS OF HERBICIDE ANALYSES OF WATER SAMPLES FROM PEDERSON PIEZOMETERS

PIEZOMETER NAME	DATE YYMMDD	DICAMBA (PPB)	MCPA (PPB)	DICLOFOP-METHYL (PPB)
SIDC	870611	<0.10	<0.10	<0.10
SIDC	870626	<0.10	<0.10	<0.10
SIDC	870707	0.14*	0.44*	<0.10
SIDC	870717	<0.10	<0.10	<0.10
NO. 3	870626	<0.10	<0.10	<0.10
NO. 3	870930	<0.10	<0.10	N/D
NO. 4	870611	0.44*	<0.10	0.42*
NO. 4	870707	<0.10	<0.10	<0.10
NO. 4	870717	<0.10	0.12*	<0.10
NO. 5	870611	<0.10	0.23*	0.54*
NO. 5	870707	<0.10	<0.10	<0.10
NO. 5	870717	<0.10	<0.10	<0.10
NO. 5	870930	<0.10	<0.10	N/D
NO. 6	870611	<0.10	0.31*	<0.10
NO. 6	870707	<0.10	<0.10	<0.10
NO. 6	870717	<0.10	<0.10	<0.10
NO. 6	870930	<0.10	<0.10	N/D
NO. 7	870611	<0.10	<0.10	<0.10
NO. 7	870707	<0.10	0.38*	<0.10
NO. 7	870717	<0.10	0.15*	<0.10
NO. 8	870611	<0.10	0.11*	<0.10
NO. 8	870707	<0.10	0.23*	0.27
NO. 8	870717	<0.10	0.22*	<0.10
NO. 8	870930	<0.10	<0.10	N/D
NO. 9	870611	<0.10	<0.10	<0.10
NO. 9	870707	<0.10	0.53*	0.12*
NO. 9	870717	<0.10	0.17*	<0.10
NO. 10	870611	<0.10	<0.10	<0.10
NO. 10	870707	<0.10	<0.10	<0.10
NO. 10	870717	<0.10	<0.10	<0.10
NO. 11	870611	<0.10	0.25*	0.17*
NO. 11	870707	<0.10	<0.10	<0.10
NO. 11	870717	<0.10	<0.10	<0.10
NO. 12	870611	<0.10	<0.10	<0.10
NO. 12	870707	<0.10	<0.10	<0.10
NO. 12	870717	<0.10	<0.10	<0.10
NO. 12	870930	<0.10	<0.10	N/D
NO. 13	870611	<0.10	<0.10	<0.10
NO. 13	870707	<0.10	0.15*	<0.10
NO. 13	870717	<0.10	<0.10	<0.10
NO. 13	870930	<0.10	<0.10	N/D

NOTES: * MEANS CONFIRMED BY GC/MS
N/D MEANS NOT DETERMINED
ALL ANALYSES BY AGRICULTURE CANADA, REGINA RESEARCH STATION, EXCEPT FOR SEPTEMBER SAMPLES WHICH WERE ANALYSED BY THE SASKATCHEWAN RESEARCH COUNCIL.

5.7.3.1 Diclofop-methyl

Water samples taken from piezometers No. 4, 5 and 11 on June 11, prior to irrigation and four days after application of Hoegrass, show detectable levels of diclofop-methyl. Since no Hoegrass was applied in 1986 (Nicholaichuk et al, 1987), and no precipitation occurred in the period June 7 - 11, it is unlikely that the observed diclofop-methyl concentration in water from these piezometers can be attributed to downward leaching. Similarly, the occurrence of this chemical in water samples taken from piezometers No. 8 and 9 on July 7, is difficult to explain. Piezometer No. 8 is located directly adjacent to the water supply canal (see Figure 3) and this piezometer site is not affected by the gravity irrigation. Consequently, contamination of water in this piezometer would require infiltration of contaminated water through the wetted perimeter of the supply canal, when filled. Since diclofop-methyl was detected only once in the irrigation water (Table 7), it appears to be unlikely that contaminated canal water is the source of contamination of the groundwater at the piezometer No. 8 site. The shallow groundwater at the piezometer No. 9 site is considered to consist largely of water which entered the shallow groundwater prior to 1953. Consequently, contamination of the shallow groundwater at this site would require mixing of infiltrating contaminated water with the older water. This hypothesis can be neither accepted or rejected.

TABLE 7 BACKGROUND HERBICIDE CONCENTRATIONS IN IRRIGATION WATER AT PEDERSON SITE

DATE	TIME	DICAMBA (PPB)	MCPA (PPB)	DICLOFOP-METHYL (PPB)
JUNE 23	13:40	<0.10	<0.10	<0.10
	16:20	<0.10	<0.10	<0.10
	18:30	<0.10	<0.10	<0.10
JUNE 24	11:35	<0.10	<0.10	<0.10
	16:50	<0.10	<0.10	0.23*
JUNE 25	08:25	<0.10	<0.10	<0.10
	10:18	<0.10	<0.10	<0.10
	13:30	<0.10	<0.10	<0.10
	14:20	<0.10	<0.10	<0.10
	16:20	<0.10	<0.10	<0.10
AUGUST 5	11:45	<0.10	<0.10	<0.10
	16:15	<0.10	<0.10	<0.10
AUGUST 6	09:20	<0.10	<0.10	<0.10
	12:20	<0.10	<0.10	<0.10
	16:15	<0.10	<0.10	<0.10
AUGUST 7	08:10	<0.10	<0.10	<0.10
	12:10	<0.10	<0.10	<0.10
	15:20	<0.10	<0.10	<0.10

NOTES: * MEANS CONFIRMED BY GC/MS ANALYSIS.
ANALYSES BY AGRICULTURE CANADA, REGINA RESEARCH STATION.

5.6.3.2 Dicamba

Dicamba was detected in a water sample taken from piezometer No. 4 on June 11, prior to application of Dyvel and prior to the first irrigation. Although Dyvel was applied in 1986 (Nicholaichuk et al, 1987), the occurrence of dicamba in this sample should be questioned since it implies that it would have to have a persistence in the saturated zone of at least 12 months. This appears to be unlikely since the available data for dicamba (Table 6) do not provide any indication of such a long persistence in the saturated zone. On the contrary, the July 7 water sample from this piezometer showed no detectable dicamba. Similarly, dicamba was found in a water sample obtained from piezometer SIDC on July 7, but was not detected in the July 17 sample.

5.7.3.3 MCPA

MCPA was detected in water samples from piezometers No. 5, 6, 8 and 11 on June 11, prior to application of Dyvel and prior to the first irrigation event. Although Dyvel was applied in 1986 (Nicholaichuk et al, 1987), the occurrence of MCPA in the June 11 water samples should be questioned since it implies that it also would have to have a persistence in the saturated zone of at least 12 months. The available data for MCPA (see Table 7) suggest that there might be some persistence but the data are inconsistent. For example, a relatively high concentration of MCPA was found in the July 7 water sample from piezometer SIDC but in the July 17 sample no MCPA was detected. On the other hand, water samples taken from piezometers No. 7, 8 and 9 show MCPA concentration above the detection limit for both the July 7 and July 17 samples.

However, the occurrences of MCPA in water from these piezometers might be questionable. The only source of contamination of the groundwater at the site of piezometer No. 8 is water infiltrating through the wetted perimeter of the supply canal but there is no evidence that this water was contaminated with MCPA (see Table 7).

The occurrence of MCPA in water from piezometer NO. 7 is difficult to explain. This piezometer, located in an opening in the caragana hedge, is completed in a sand at a depth of 6.5 metres below ground surface and the water level at this site is typically about 5.5 metres below ground surface. Since the piezometer site is not flooded during irrigation events, it is implied that contamination of groundwater at this site only can by explained by a very rapid downward movement of MCPA contaminated water in the vicinity of the piezometer site and lateral movement to the piezometer site. At the present there is insufficient information available to confirm or reject this pathway of contaminant migration.

Since groundwater at the piezometer No. 9 site is considered to consist largely of water which entered the shallow groundwater system prior to 1953, the observed contamination would require mixing of old water with a small amount of MCPA contaminated water. This hypothesis can neither be accepted or rejected.

6. SASKATCHEWAN IRRIGATION DEVELOPMENT CENTRE (SIDC)

6.1 Introduction

The Saskatchewan Irrigation Development Centre, in the text referred to as SIDC site, is located at SW-15-29-08-W3 and LSD-02-15-29-08-W3 (see Figure 1). The site covers an area of 80 ha. The topographical elevation may range from 501 to 504 m. A detailed topographical map for the site was prepared by the PFRA (1988).

The SIDC site was selected as a study site because its geological and hydrogeological setting was well documented (Jones and Lebedin, 1986). Secondly, excellent information was available regarding the types and amounts of herbicides applied over the years and the amounts of irrigation applied.

At the SIDC site different herbicides are applied to the various fields in which the site has been subdivided and different irrigation methods are used. Prior to 1986 the site was irrigated with the flooding method but at present gravity, central pivot and wheel line irrigation is used. The amount of irrigation applied during the period May - September varied from field to field and from crop to crop and ranged between 13.5 to 333 mm. During the same period 235 mm of precipitation was recorded at the Outlook meteorological station, located at the SIDC site (personal communication, L. Tollefson).

Because of the variety in herbicides used at the site and the different irrigation methods, the 1987 study was of a reconnaissance type.

All the data collected for the site are included in the separate appendix accompanying this report (Maathuis, 1988).

6.2 Geology

From a regional point of view, the geological setting beneath the SIDC site is similar to that at the Pederson site (see Figure 2). As far as the present study is concerned, only the Surficial Stratified Drift unit is of importance. The Surficial Stratified Drift at the site may range in thickness from about 2 to 5.5 m and is underlain by till which, at least at the top, is weathered and fractured. The Surficial Stratified Drift forms a complex stratigraphical unit which, in ascending order, may include lacustrine clays, lacustrine/deltaic sands and silts, and eolian deposits. The lacustrine and lacustrine/deltaic sediments were deposited at the site during the final deglaciation of the Outlook area (Christiansen, 1987). The contact between the till and the overlying lacustrine clays is sharp as is the contact between the clays and the lacustrine/deltaic silts and sands.

The lacustrine clays show often evidence of cyclic sedimentation. The lacustrine/deltaic deposits form a heterogeneous unit composed of sands and silts which show some upward coarsening. As shown in the cross sections presented by Jones and Lebedin (1986), and Stushnoff and Acton (1987), the distribution and thickness of the lacustrine clays and lacustrine/deltaic silts and sands varies significantly, both laterally and vertically. The occurrence of eolian deposits is limited to the southern and eastern fringes of the site.

The geological setting at the sites of the piezometers installed for the present study are presented by Maathuis (1988). Selected auger-flight samples were analysed for %wt organic carbon and for grainsize distribution. These data are also presented by Maathuis (1988).

6.3 Soils

The SIDC site occurs in the Dark Brown soil zone. Soils at the site are of the Bradwell and Asquith Associations which were described by Ellis et al (1968). Stushnoff and Acton (1987) provide a detailed soils map for the site. This map shows that the Bradwell soils are the dominant soils type and that Asquith soils only occur along the southern fringe of the site. Data provided by Stushnoff and Acton (1987) indicate that the surface material can be classified as a fine loam to a coarse silt. The organic carbon content in the upper 130 cm may range from 2.3 to 23.2 gr/kg (0.23 to 2.32 %wt) and decreases with depth (Stushnoff and Acton, 1987).

6.4 Piezometer Installation

Although a large number of piezometers were completed at the site (Jones and Lebedin, 1986), these piezometers are used solely for water level measurements and were not available for sampling. Consequently, ten additional piezometers were constructed for obtaining water samples for pesticide analyses and for water level measurements. The location of these piezometers, referred to as piezometers S01 to S10, is shown in Figure 8. The existing piezometers at the site are referred to as the C piezometers.

Based on the geological setting it was decided to place the bottom of the piezometers on the top of the lacustrine clays or on top of the till if the clay unit was thin or missing. At each piezometer site typically a 9.84 cm diameter hole was drilled, using a cable tool rig, to obtain information on the geological setting at the site.

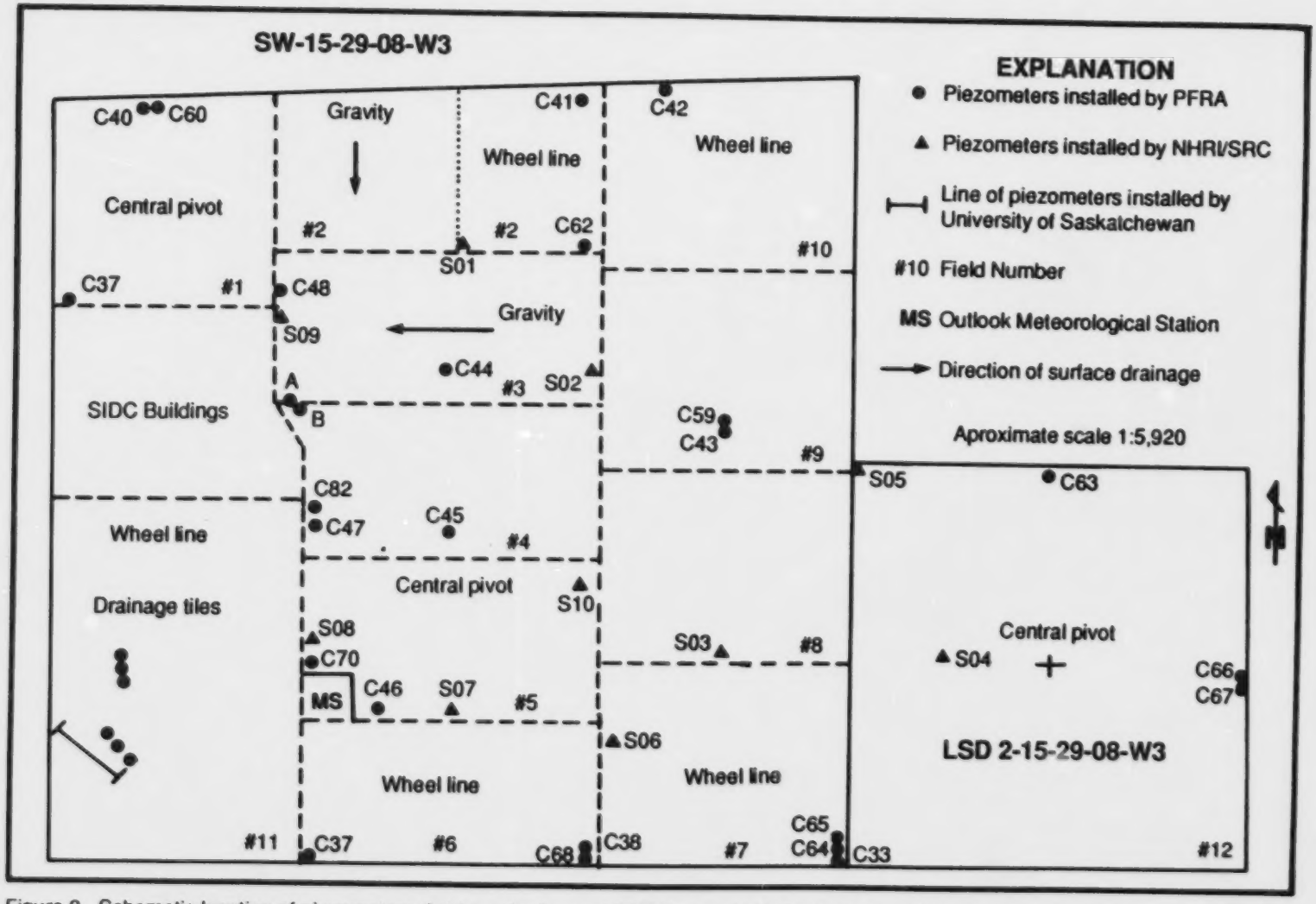

Figure 8. Schematic location of piezometers, field numbering and irrigation method, Saskatchewan Irrigation Development Centre, Outlook.

Subsequently, at most sites, the hole was reamed out to a 14.92 cm diameter. The piezometer assembly consisted of a 50 mm diameter, 750 mm long, slot #10, stainless steel screen and schedule 40, PVC casing. If the testhole was deeper than the intended depth of completion,the hole was backfilled with cuttings and 4.5 L of bentonite pellets was placed on top of it. The screen section and the lower portion of the casing was gravel packed with 20 -40 frac sand. Bentonite pellets (4.5 L) were place on top of the gravel pack and the remainder of the annulus was filled to the ground surface with a heavy bentonite slurry.

Piezometer construction and completion details are documented on the testhole logs provided by Maathuis (1988). Data on depth of piezometers and stratigraphy of completion zones are provided in Table 8.

6.5 Water Level Observations

During the period May - September, the water level in piezometers S01 to S10 was measured every 7 to 10 days. In addition, the water level in all the piezometers at the site was measured once a month. A Keck - Stevens recorder system was installed on piezometer S10 to obtain a continuous water level record for the entire crop season. However, only a continuous record for the first month of recording was obtained, due to malfunction of the Keck.

TABLE 8 DEPTH AND STRATIGRAPHY OF COMPLETION ZONE OF PIEZOMETERS AT SIDC SITE

PIEZOMETER NAME	BOTTOM PIEZ. BELOW GROUND SURFACE (M)	STRATIGRAPHY OF COMPLETION ZONE
S 01	2.96	Surficial Stratified Drift
S 02	3.66	Surficial Stratified Drift
S 03	2.36	Surficial Stratified Drift
S 04	2.37	Surficial Stratified Drift
S 05	4.23	Surficial Stratified Drift
S 06	4.05	Surficial Stratified Drift
S 07	4.16	Surficial Stratified Drift
S 08	2.74	Surficial Stratified Drift
S 09	2.24	Surficial Stratified Drift
S 10	3.75	Surficial Stratified Drift

A listing of the water level data is provided by Maathuis (1988). Hydrographs for the piezometers S01 to S10 are included in appendix B of this report. Jones and Lebedin (1986, Appendix B) presented hydrographs for the existing piezometers at the site, covering the period 1985 - 1986.

6.5.1 Groundwater Flow Regime

The shallow groundwater flow system has been described by Jones and Lebedin (1986). A re-evaluation of this system, using water level data for all the piezometers at the site in 1987, has not been attempted since at the time of preparing this report for many piezometers no surveyed elevations of the top of the piezometers were available.

The shallow groundwater flow system is probably controlled by input from snowmelt and irrigation and output by evapotranspiration. It is expected that lateral and vertical flow only plays a minor role in the overall shallow groundwater flow regime. The impact of drainage tiles on water levels in the drained area (see Figure 8) and on the groundwater flow regime at the entire site can not be assessed. It also should be noted that the switch from flood irrigation to a mixture of different irrigation methods and the elimination of a network of water supply ditches may have had a significant impact on the shallow groundwater flow regime.

6.5.2 Hydrograph Interpretation

The hydrographs (see Appendix B) for the piezometers installed for the present show that during the period of observation the water level in the piezometers fluctuated over a range from a few decimeters up to 1 metre. The highest water levels are typically reached in the period June- August. However, due to the short period of data available, it can not be established whether or not these water level highs are related to recharge derived from snowmelt or irrigation, or a combination of both.

6.6 Water Quality

Piezometers S01 - S10 were equipped with narrow diameter Teflon tubing to reduce chances of cross contamination during sampling. The sampling procedures were the same as used at the Pederson site (see section 5.7). No samples were taken for stable isotope analyses. It should be noted that no water samples were obtained from piezometers S03 and S08 since these piezometers were dry throughout virtually the entire period of observation.

6.6.1 Major Ion Analyses

The results of the chemical analyses for major ions are shown in Table 9 and Figure 9. The data show that shallow groundwater at the site is of the calcium/magnesium - sulphate type and that the sum of ions may range from 2,880 to 12,300 mg/L. Similar as at the Pederson site, the water quality data show a significant spatial variation in hydro-chemistry.

TABLE 9 MAJOR ION DATA FOR WATER FROM SELECTED PIEZOMETERS AT SIDC SITE.

PIEZ. NAME	DEPTH M	DATE YYMMDD	pH LAB	CA MG/L	CA (HCL) MG/L	MG MG/L	NA MG/L	K MG/L	FE MG/L	MN MG/L	HCO3 MG/L	SO4 MG/L	CL MG/L	NH4-N MG/L	NO3-N MG/L	KJELD. -N MG/L	TOT. -N MG/L	PO4-P MG/L	TOT. P MG/L	TOT. C MG/L	TOT. INORG. MG/L	TOT. ORG. C MG/L	SUM IONS MG/L	COND. MG/L	T.H. CACO3 MG/L	T.A CACO3 MG/L	ERROR BAL %
S 02	4.14	870508	7.43	142	147	390	52	8.6	<0.01	0.10	1130	845	35	N/D	63	N/D	N/D	<0.01	N/D	240	232	8	2882	3000	1960	930	0.06
S 06	4.63	870508	7.54	453	454	826	980	13	<0.01	0.03	1260	5130	340	N/D	0.11	N/D	N/D	<0.01	N/D	424	260	164	9003	8260	4530	1030	1.31
S 07	4.62	870508	7.48	636	636	368	254	14	<0.01	0.24	1240	2480	79	N/D	4.5	N/D	N/D	<0.01	N/D	294	244	50	5091	4700	3100	1020	0.74
S 09	2.63	870625	7.52	459	N/D	1240	1390	23	N/D	N/D	1370	6920	476	0.29	99	8.2	107	0.04	0.14	400	220	180	12317	11100	6260	1120	0.29
S 10	4.17	870508	7.64	537	N/D	213	60	9	N/D	N/D	699	1780	9	N/D	N/D	N/D	N/D	N/D	N/D	N/D	N/D	N/D	3307	3190	2210	573	1.68

NOTES: N/D MEANS NOT DETERMINED
IN CALCULATING SUM OF IONS NO3-N WAS CONVERTED TO NO3-NO3
ANALYSES BY SASKATCHEWAN RESEARCH COUNCIL

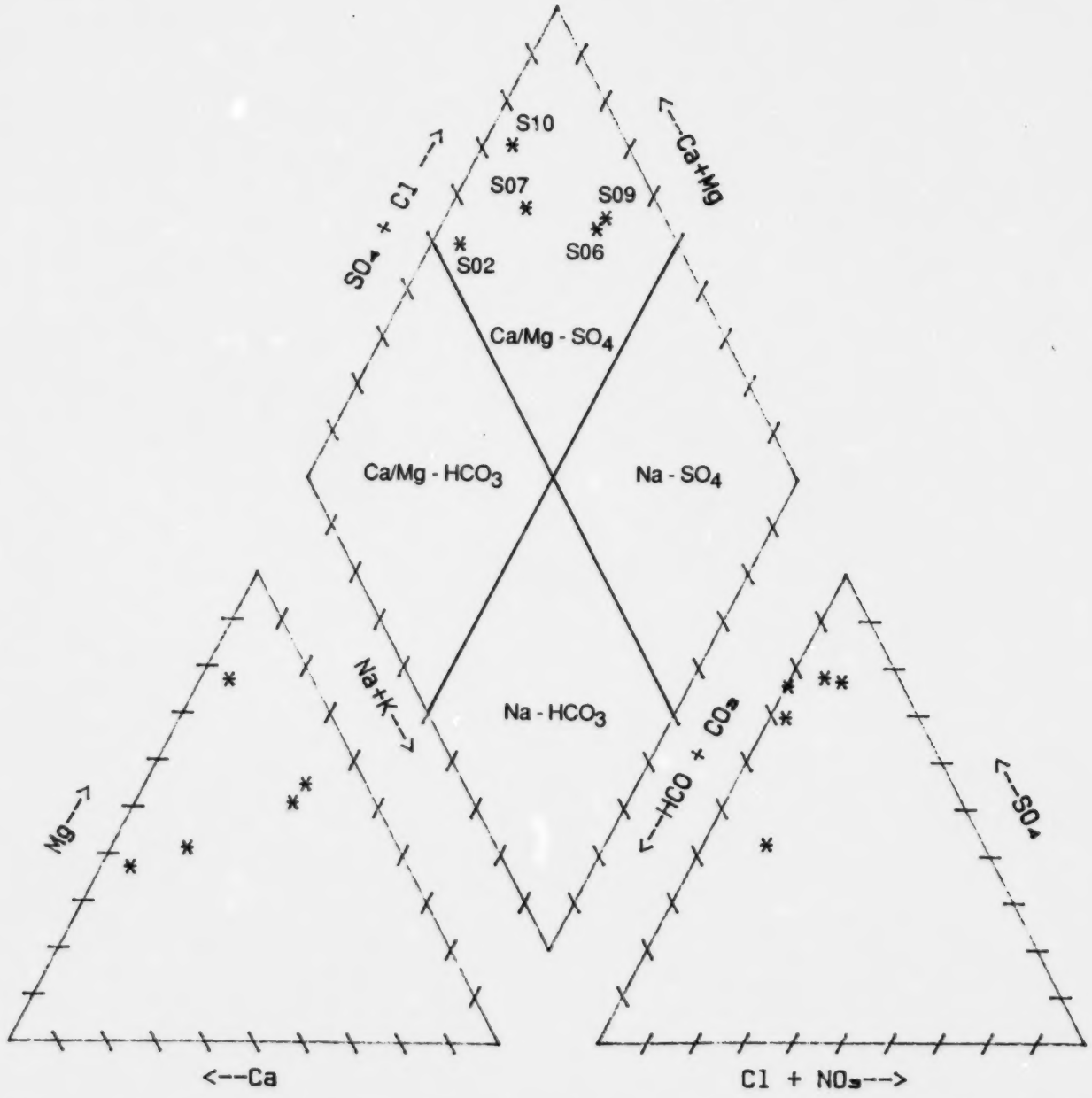

FIGURE 9 PIPER-PLOT OF WATER QUALITY DATA FOR SELECTED PIEZOMETERS AT SIDC SITE.

6.6.2 Herbicides

The types of herbicides applied on the site in the past 6 years are listed in Table 10. In 1987 the herbicides were applied in the period May 4 - June 26. A detailed listing of the date of application is presented by Maathuis (1988). Groundwater samples from selected sampling events were analysed for the herbicides trifluralin, triallate, dicamba, bromoxynil, 2,4-D and diclofop-methyl. The results of the analyses are listed in Table 11.

6.6.2.1 Trifluralin, Dicamba and Bromoxynil

The samples analysed showed no detectable concentrations of the herbicides trifluralin, dicamba and bromoxynil.

6.6.2.2 Triallate

Detectable concentrations of the herbicide triallate (Avadex) were observed in water samples from piezometers S01 and S10.

There is no obvious explanation for the occurrence of this herbicide in the shallow groundwater at these piezometer sites, in particular since the product Avadex has not been applied in the past few years to the fields surrounding these piezometers.

TABLE 10 HERBICIDES APPLIED AT SIDC SITE IN PERIOD 1982 - 1987.

FIELD	1982	1983	1984	1985	1986	1987
1	Eradicane Banvel 2,4-D		Treflan Amiben	Eradicane Buctril M	Eradicane Buctril M Bromoxynil MCPA	Eradicane Poast Treflan Buctril M
2	Buctril M	Treflan Sencor	Hoegrass II	Hoegrass II	Bromoxynil MCPA	Eptam Torch Hoegrass Treflan
3	Amiben Basagran Assist Treflan	Eradicane Banvel		Buctril M	Hoegrass	Hoegrass Torch
4	Avadex Glean Treflan	Buctril M	Avadex Treflan Buctril M	Sencor Poast Assist		
5			Cobutox			
6	Hoegrass Glean	Avadex Treflan Buctril M	Avadex Treflan Buctril M	Avadex Treflan Buctril M		Malathion Treflan 2,4-D B
7	Avadex Glean Treflan	Avadex Treflan Buctril M		Avadex Treflan Hoegrass II	Bayleton Tilt Cycocel Terpal C Propiconazole Ethepon	Poast Torch Hoegrass
8	Sencor WP		Cobutox Poast		Hoegrass Bromoxynil Maneb Carbathiin Flutriafol MCPA Tilt Cycocel Diclofop-methyl	Hoegrass Torch
9				Hoegrass II	Poast Triafluralin Bromoxynil MCPA Metribuzin	2,4-D, amine
10	Avadex BW Buctril M	Treflan Sencor WP	Poast Assist Buctril M	Treflan Poast	Bromoxynil MCPA Micro-mist	Poast Treflan Sencor
11			Avadex Treflan Buctril M		Hoegrass Bromoxynil	2,4-D,amine
12					Hoegrass Bromoxynil	Hoegrass Hoegrass II Treflan Poast

TABLE 11 RESULTS OF HERBICIDE ANALYSES OF WATER SAMPLES FROM SELECTED SIDC PIEZOMETERS.

PIEZOMETER NAME	DATE YYMMDD	TRIF. (1) PPB	TRI. (2) PPB	DICAMBA PPB	BROMOX. (3) PPB	2,4-D PPB	DICLOFOP-METHYL PPB
S-01	870728	<0.10	0.13	<0.10	<0.10	0.21*	<0.10
S-02	870625	<0.10	<0.10	<0.10	<0.10	<0.10	0.24*
S-02	870728	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10
S-04	870806	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10
S-05	870728	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10
S-06	870626	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10
S-06	870728	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10
S-07	870625	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10
S-07	870725	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10
S-09	870625	<0.10	<0.10	<0.10	<0.10	0.66*	<0.10
S-09	870728	<0.10	<0.10	<0.10	<0.10	0.10	<0.10
S-10	870626	<0.10	0.17	<0.10	<0.10	<0.10	<0.10
S-10	870806	<0.10	0.39*	<0.10	<0.10	<0.10	<0.10

NOTES: * Means confirmed by GC/MS
(1) Trifluralin
(2) Trialate
(3) Bromoxynil
Analyses by Agriculture Canada, Regina Research Station.

6.6.2.3 2,4-D

Detectable concentrations of the herbicide 2,4-D were found in water samples from piezometers S01 and S09. Since 1982, 2,4-D has not been applied on the fields surrounding these piezometers. Consequently, there is no obvious explanation for the occurrences of this herbicide in the shallow groundwater at these piezometer sites.

6.6.2.4 Diclofop-methyl

The herbicide diclofop-methyl was detected only once, in the June 25 water sample from piezometer S02. Hoegrass was applied in 1986 and 1987 on fields No. 3 and 8 which are in the immediate vicinity of this piezometer. However, the hypothesis that the occurrence of this herbicide in shallow groundwater at this piezometer site is caused by downward leaching beneath fields 3 and 8 and by lateral flow, can neither be accepted or rejected.

7. KONST SITE

7.1 Introduction

The area covered by Sections 1, 2, 3 and the southern halves of Sections 10, 11, and 12, Township 30, Range 8, is referred to as the Konst site (see Figure 1). The area covers about 11 square kilometres and is occupied by various landowners, including Mr. J. Konst.

The topographical elevation of the area may range from 536 m ASL at the eastern boundary to 518 m ASL at the edge of the South Sakatchewan River Valley (personal communication, C. Rogal). A roughly south - north running topographical depression occurs ion the middle of Sections 1 and 12.

Since the area is studied by the Saskatchewan Water Corporation (SWC), West Central Region, the geological and hydrogeological setting was known and piezometers were available for sampling. The location of piezometers, the land use and herbicide use is shown in Figure 10. The land and herbicide use in 1987 is based on information provided by the landowners when surveyed in May 1987. Because of the diversity in land and herbicide use and the wide spread location of the piezometers, the 1987 study had to be of a reconnaissance type.

Data collected for the Konst site are presented by Maathuis (1988).

7.2 Geology

From a regional point of view, the geological setting beneath the Konst site is similar to that beneath the Pederson and SIDC sites. However, the composition of the Surficial Stratified Drift differs significantly from the other sites. The Surficial Stratified Drift at

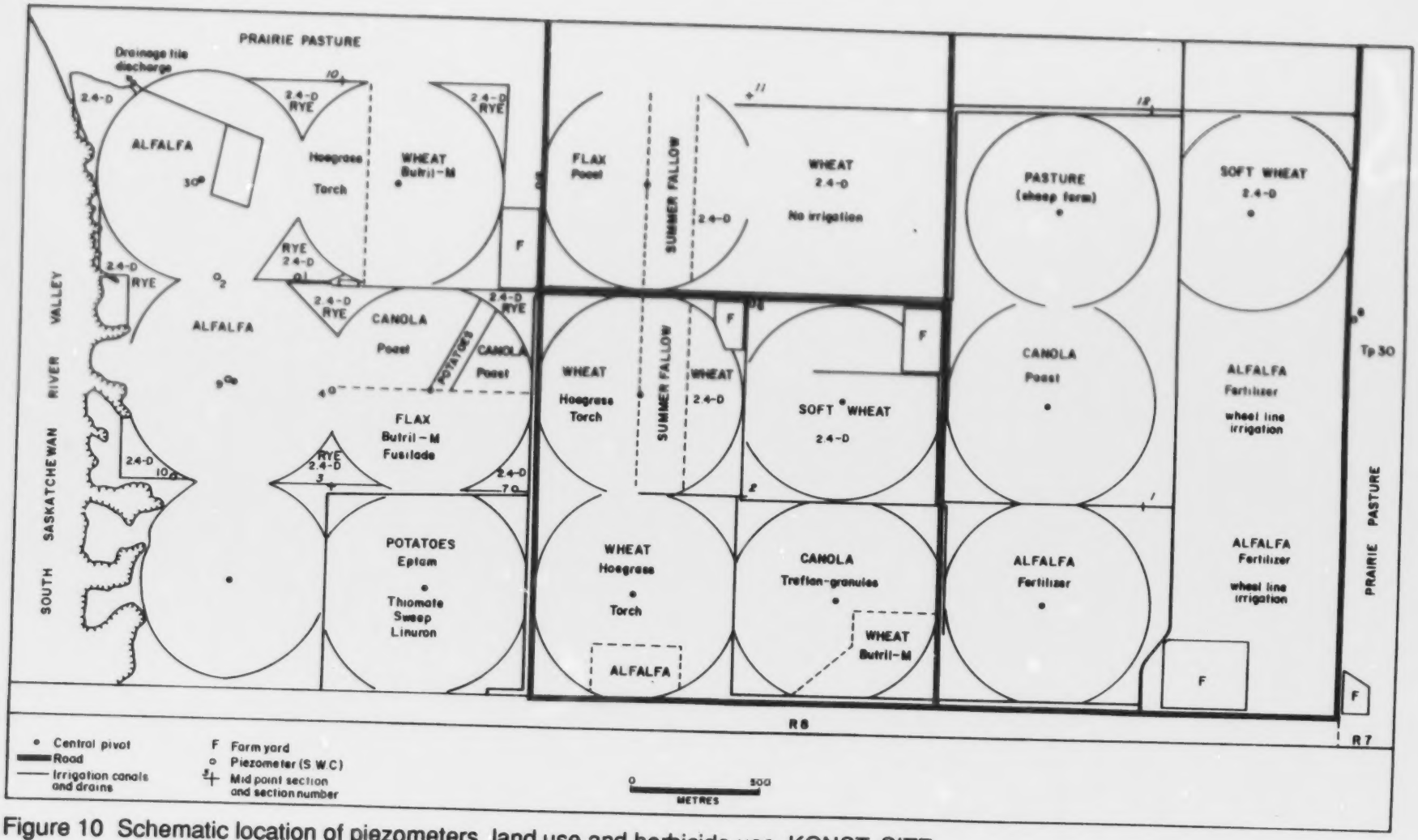

Figure 10 Schematic location of piezometers, land use and herbicide use, KONST SITE

the Konst site, in ascending order, may include lacustrine silts and clays, deltaic and fluvial sand and gravels and eolian silts and sands (Christiansen, 1984, 1987). The thickness of the Surficial Stratified Drift may range from about 5 to 20 metres. The Surficial Stratified Drift is underlain by till. The deltaic and fluvial sands and gravels form an unnamed aquifer which is used for private water supplies.

7.3 Soils

The Konst site occurs in the Dark Brown soil zone. Soils at the site are of the Asquith and Bradwell Associations, described by Ellis et al (1968).

7.4 Piezometer Installation

The existing piezometers at the site were constructed in the fall of 1984. Typically, at each piezometer site an augerhole was drilled and samples were collected to establish the geological setting. A typical piezometer assembly consists of a 50 mm diameter, slot #10, PVC screen and 38 mm diameter, schedule 80, PVC casing. The screen section and the lower part of the casing generally were gravel packed, using 12 -20 frac sand. The annulus was backfilled with auger cuttings to a depth of 1 metre below ground surface and the remainder of the hole was filled with bentonite pellets. Piezometer construction details, provided by SWC, are included in Maathuis(1988). Data on piezometer depth and stratigraphy of the completion zones are provided in Table 12.

TABLE 12 DEPTH AND STRATIGRAPHY OF COMPLETION ZONE OF SELECTED PIEZOMETERS AT KONST SITE

PIEZOMETER NAME	BOTTOM PIEZ. BELOW GROUND SURFACE (M)	STRATIGRAPHY OF COMPLETION ZONE
SWC 01	7.92	Surficial Stratified Drift
SWC 04	6.86	Surficial Stratified Drift
SWC 05	8.63	Surficial Stratified Drift
SWC 06	7.68	Surficial Stratified Drift
SWC 07	7.92	Surficial Stratified Drift
SWC 08	4.40	Surficial Stratified Drift
SWC 09	6.18	Surficial Stratified Drift

7.5 Water Level Observations

Water level data, collected by SWC and dating back to 1985, are available for the piezometers. During the period May - September, 1987, the water level in selected piezometers was measured every 7 to 10 days, in addition to the regular measurements made by SWC. A Keck-Stevens recorder system was installed on piezometer SWC 05 to obtain a continuous water level record for the entire crop season. A listing of available water level, and the records from the recorder, are provided by Maathuis (1988).

7.5.1 Groundwater Flow Regime

Piezometer water levels as well as point water level measurements in uncased auger testholes indicate that in the fall of 1985 the following groundwater flow conditions existed (personal communication, C. Rogal):

- A groundwater divide exist which runs more or less through the sites of piezometers SWC 06 and 07.
- West of the divide flow is toward the South Saskatchewan River Valley.
- East if the divide there is an eastward flow toward the middle of Sections 1 and 12 and flow in the middle of these Sections is either to the north or south.
- Across the eastern boundary of the area there is a westward flow toward the middle of Sections 1 and 12.

It should be realised that the above description of the groundwater flow system represents an instantaneous picture at a particular time and may not be representative for the conditions which prevailed during the period May - September 1987. In particular there is uncertainty with regard to the existence and location of the groundwater divide.

Groundwater recharge is derived from snowmelt and irrigation. Recharge from irrigation may include recharge derived from the central pivot systems and/or charge from canal seepage, both from water supply as well as drainage canals. Although the major water supply canals have been lined, it should be noted that even lined canals can be expected to leak to some degree (Wachyan and Rushton, 1987).

7.5.2 Hydrograph Interpretation

Hydrographs for the piezometers included in the water sampling program are included in Appendix C of this report. Water levels in surficial aquifers in Saskatchewan show a typical behavior of reaching a seasonal minimum just prior to the snowmelt (February - April) and a maximum in the period May - July, followed by a systematic decline (Maathuis and van der Kamp, 1986). The water levels in the SWC piezometers show a somewhat different behavior. The seasonal minimum occurs in May - June and the water level in most piezometers remains high for up to three month rather than showing a pronounced maximum in one particular month. The delay between snowmelt and water level response is probably due to thickness of the unsaturated zone and its lithological

composition. The extended period of high water levels probably reflects recharge from irrigation and/or recharge from canal seepage. However, this has not been proven.

7.6 Water Quality

The water quality program consisted of obtaining water samples from piezometers SWC 01, SWC 04, SWC 05, SWC 05, SWC 06,SWC 07 and SWC 09 and from the irrigation canals near SWC 06 and 07 (see Figure 10).

The piezometers were extensively pumped with a centrifugal pump prior to the first sampling event. Subsequently, the piezometers were equipped with small diameter Teflon tubing. The sampling procedures were the same as described in Section 5.7 of this report.

7.6.1 Major Ion Analyses

The results of the chemical analyses for major ions are shown in Table 13 and in Figure 11. In contrast to the Pederson and SIDC sites where shallow groundwater is of the calcium/magnesium - sulphate type and is highly mineralised, at the Konst site the shallow groundwater is predominantly of the calcium/magnesium - bicarbonate type which has a sum of ions ranging from 440 to 1230 mg/l. The water quality characteristics at the Konst site are indicative of a well-flushed system.

TABLE 13 MAJOR ION DATA FOR WATER FROM SELECTED PIEZOMETERS AT KONST SITE AND FOR WATER FROM IRRIGATION CANAL.

PIEZ. NAME	DEPTH M	DATE YYMMDD	pH LAB	CA MG/L	CA (HCL) MG/L	MG MG/L	NA MG/L	K MG/L	FE MG/L	MN MG/L	HCO3 MG/L	SO4 MG/L	CL MG/L	NH4-N MG/L	NO3-N MG/L	KJELD. -N MG/L	TOT. -N MG/L	PO4-P MG/L	TOT. P MG/L	TOT. C MG/L	TOT. INORG. MG/L	TOT. ORG. C MG/L	SUM IONS MG/L	COND. MG/L	T.H. CACO3 MG/L	T.A CACO3 MG/L	ERROR BAL %
SWC 01	8.54	870612	8.12	85	86	27	20	3.7	<0.01	<0.01	221	160	6.2	0.06	0.66	0.14	0.8	<0.01	0.02	45	39	6	526	651	323	181	1.72
SWC 04	7.09	870612	8.09	136	137	52	47	4.2	<0.01	<0.01	460	226	12	0.07	2.1	0.46	2.6	<0.01	0.02	104	90	14	947	1070	553	377	1.86
SWC 05	9.18	870612	8.12	105	105	33	20	3.4	<0.01	0.06	332	145	6.1	0.08	0.09	0.24	0.33	<0.01	0.24	68	61	7	645	750	398	272	1.55
SWC 06	8.38	870611	8.05	108	106	38	33	3.4	0.18	0.01	347	143	23	0.08	4.6	0.45	5	<0.01	0.03	73	64	9	716	855	424	284	2.01
SWC 07	8.90	870612	8.00	65	67	20	23	3.2	<0.01	<0.01	245	77	6.1	0.08	0.03	0.17	0.2	<0.01	0.02	51	45	6	440	538	246	201	1.51
SWC 08	5.15	870611	7.94	115	117	42	26	2.4	<0.01	0.09	383	187	2.3	0.05	0.18	0.08	0.26	<0.01	0.02	75	72	3	759	861	461	314	0.66
SWC 09	7.14	870612	7.96	172	176	78	63	4.4	<0.01	0.06	329	565	20	0.10	<0.005	0.52	0.52	<0.01	0.01	74	61	13	1232	1430	747	270	0.37
I.C. 07		870612	8.40	42	43	18	21	2.7	<0.01	<0.01	185	67	5.7	0.11	0.007	0.43	0.44	<0.01	0.02	38	29	9	342	415	180	152	0.33
KONST	4.57	870508	7.74	61	73	14	24	3.3	0.04	0.06	205	73	8	N/D	0.12	N/D	N/D	<0.01	N/D	43	43	<1	389	487	209	168	2.01

NOTES: N/D MEANS NOT DETERMINED
IN CALCULATING SUM OF IONS NO3-N WAS CONVERTED TO NO3-NO3
I.C. 07 SURFACE WATER SAMPLE FROM IRRIGATION CANAL NEAR SWC 07
KONST MEANS KONST FARM WELL
ANALYSES BY SASKATCHEWAN RESEARCH COUNCIL

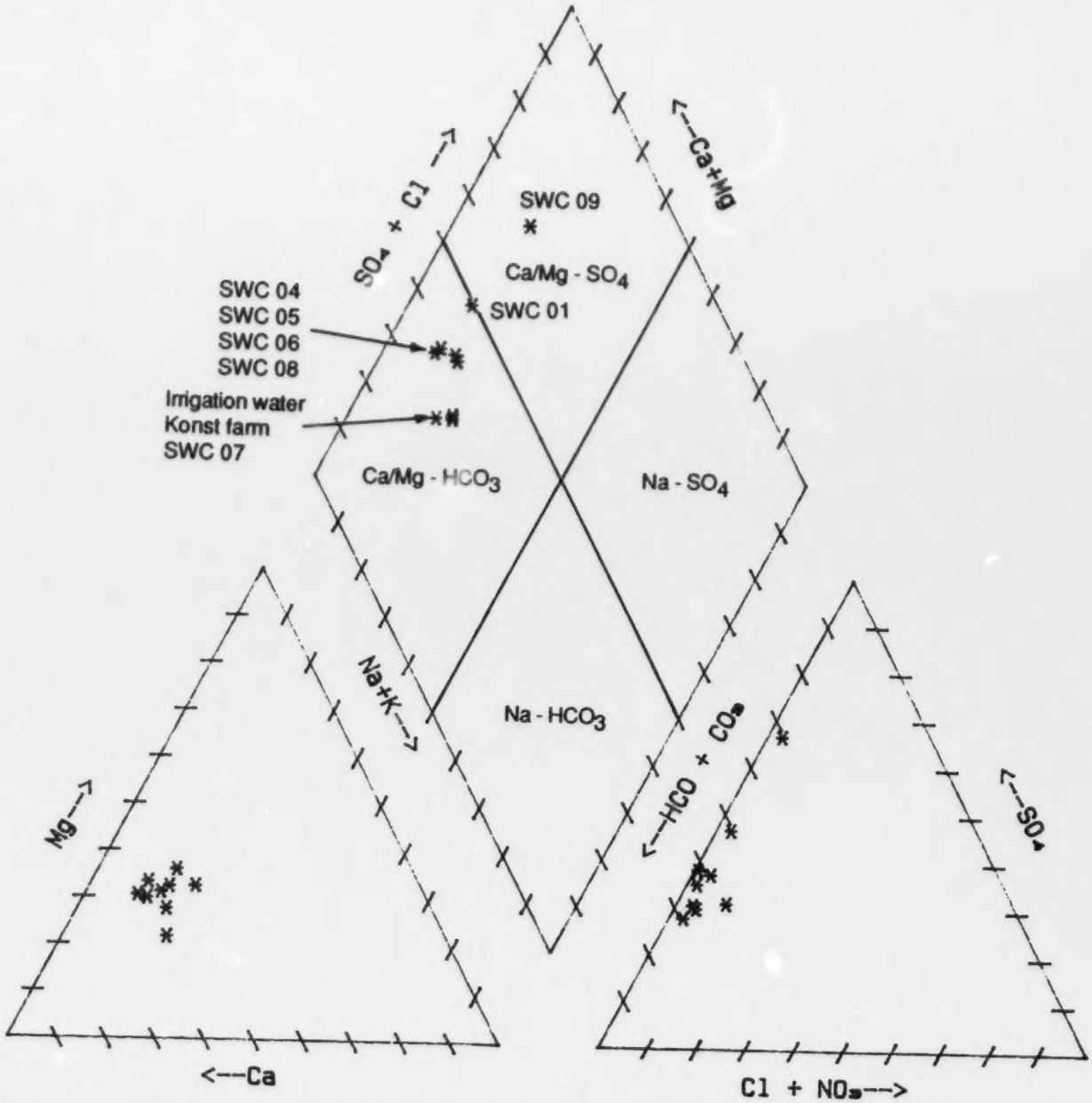

FIGURE 11 PIPER-PLOT OF WATER QUALITY DATA FOR KONST PIEZOMETERS, KONST FARM WELL AND FOR IRRIGATION CANAL WATER.

7.6.2 Isotope Analysis

Selected groundwater samples and a water sample from an irrigation canal were analysed for oxygen-18 and deuterium (Table 14). The data suggest that here might be a significant variation in the distribution of the isotopes. However, there are insufficient data to explain the significance of this variation.

7.6.3 Herbicide Analyses

The type of herbicides applied on the site in 1987 are shown in Figure 10. Water samples from selected piezometers and irrigation canals were analysed for the herbicides trifluralin, triallate, dicamba, bromoxynil, 2,4-D and diclofop-methyl. The results of the analyses are shown in Table 15.

7.6.3.1 Herbicides in Surface Water

Since both irrigation water supply and drainage canals can be expected to leak to some degree, the water supply canals near piezometers SWC 06 and 07 were sampled to establish whether or not seepage waters should be considered as a potential source contributing to contamination of the shallow groundwater. As is shown in Table 15, detectable concentrations of the herbicides triallate, 2,4-D and diclofop-methyl were found in the irrigation canals sampled. The concentrations of the herbicides are similar to those found in other, unpublished, studies (personal communication, R. Grover). it should be noted that Avadex, assumed to be the source of triallate, was not used in the study area. The likely source of the herbicides detected in the

TABLE 14 STABLE ISOTOPE DATA FOR WATER FROM SELECTED PIEZOMETERS AT KONST SITE AND FOR IRRIGATION WATER

SITE	DELTA-D	DELTA-018
IRR.C. SWC 07	-122	-16.0
SWC 07	-118	-15.6
SWC 01	-118	-15.7
SWC 05	-166	-20.5

NOTES: IRR.C. Irrigation canal near piezometer site SWC 07
Analyses by Department of Geological Sciences, University of Saskatchewan

TABLE 15 RESULTS OF HERBICIDE ANALYSES OF WATER SAMPLES FROM SELECTED PIEZOMETER AT KONST SITE AND FROM IRRIGATION CANALS.

SAMPLE SITE	DATE YYMMDD	TRIF. (1) PPB	TRI. (2) PPB	DICAMBA PPB	BROMOX. (3) PPB	2,4-D PPB	DICLOFOP-METHYL PPB
IR.C. SWC 06	870624	<0.10	<0.10	<0.10	<0.10	0.57*	0.15*
IR.C. SWC 06	870727	<0.10	0.14*	<0.10	<0.10	0.18*	0.21*
IR.C. SWC 07	870709	<0.10	<0.10	<0.10	<0.10	1.65*	0.24*
IR.C. SWC 07	870727	<0.10	0.15	<0.10	<0.10	0.17*	<0.10
SWC 01	870709	<0.10	<0.10	<0.10	<0.10	0.12*	0.22*
SWC 01	870728	<0.10	<0.10	<0.10	<0.10	0.10	<0.10
SWC 04	870624	<0.10	<0.10	<0.10	<0.10	<0.10	0.23*
SWC 04	870728	<0.10	<0.10	<0.10	<0.10	0.12*	<0.10
SWC 05	870625	<0.10	<0.10	<0.10	<0.10	0.11*	<0.10
SWC 06	870709	<0.10	0.14*	<0.10	<0.10	<0.10	<0.10
SWC 06	870727	<0.10	<0.10	<0.10	<0.10	0.14	<0.10
SWC 07	870709	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10
SWC 07	870814	<0.10	0.13*	<0.10	<0.10	<0.10	<0.10
SWC 07	870827	<0.10	<0.10	<0.10	<0.10	0.11*	<0.10
SWC 08	870709	<0.10	<0.10	<0.10	<0.10	0.12*	<0.10
SWC 08	870827	<0.10	0.13*	<0.10	<0.10	0.15*	0.13*
SWC 09	870624	<0.10	<0.10	<0.10	<0.10	<0.10	0.17*
SWC 09	870728	<0.10	<0.10	<0.10	<0.10	<0.10	0.12*

NOTES: * means confirmed by GC/MS
(1) Trifluralin
(2) Trialate
(3) Bromoxynil
IR.C. SWC 06/07 Surface water sample from irrigation canal near piezometers SWC 06 and 07.
Analyses by Agriculture Canada, Regina Research Station.

canal water is spray drift, deposited directly on the water. However, there is no information to substantiate or reject this hypothesis nor is it known how wide spread or limited contamination of canal water is.

7.6.3.2 Trifluralin, Dicamba and Bromoxynil

Both the surface water and groundwater samples analysed show no detectable levels of trifluralin, dicamba and bromoxynil.

7.6.3.3 Triallate

Detectable concentrations of the herbicide triallate were found in some of the water samples from piezometers SWC 06, 07, and 08. The occurrence of triallate in water from piezometers SWC 06 and 07 might be related to the presence of triallate in the water of nearby irrigation canals. However, this can not be proven without further detailed studies. Again, it should be noted that Avadex, assumed to be the source of the triallate, was not used in the study area in 1987.

There is no obvious explanation for the occurrence of triallate in water from piezometer SWC 08. The piezometer is located in an area of westward groundwater flow and the area to the east of the piezometer is used as pasture land.

7.6.3.4 2,4-D

Water samples from all the piezometers, except SWC 09, show at least once detectable concentrations of the herbicide 2,4-D.

As with the herbicide triallate, the occurrence of 2,4-D in water from piezometers SWC 06 and 07 may or may not be related to the nearby

irrigation canals. The herbicide 2,4-D was also applied on land in the near vicinity of these piezometers. However, it can neither be substantiated nor rejected that it can be attributed to downward leaching through the unsaturated zone and lateral movement within the saturated zone.

Both the July and August water samples from SWC 08 show detectable levels of 2,4-D. This occurrence is difficult to explain because of the westward groundwater flow in the area and the pasture land to the east of the piezometer site.

The herbicide 2,4-D was applied in the vicinity of piezometers SWC 01, 04 and 05. However, when considering downward leaching through the unsaturated zone and lateral movement within the saturated zone, it should be questioned whether or not the detected concentrations can be attributed to the 2,4-D applied in 1987.

7.6.3.5 Diclofop-methyl

The herbicide diclofop-methyl was detected in some of the water samples from piezometers SWC 01, 04, 08 and 09. It appears to be unlikely that the occurrences in shallow groundwater at the sites of SWC 01, 04 and 09 can be directly attributed to downward leaching in the areas where it was applied in 1987 and to lateral movement away from those areas.

A water sample from SWC 08 also shows detectable diclofop-methyl. However, again it should be noted that groundwater flow in the area of the piezometer is to the west and that to the east the land is used as pasture land.

8. DISCUSSION AND CONCLUSIONS

Analyses of water samples obtained from shallow piezometers at the three sites investigated show an erratic presence of herbicides at very low concentrations (0.1 to 1 ppb). However, in most, if not in all, of the cases when herbicides were found to be present in the water samples its presence can not be positively attributed to downward leaching through the unsaturated zone and/or to lateral flow within the saturated zone of the herbicides applied on the land in 1987. Based on considerations such as type of herbicide detected, date(s) and location of application, date(s) of detection and the inconsistencies in the persistence of detected herbicides in the saturated zone, it is suggested that in most cases the observed contamination might be due to other causes. These causes may include:

- contamination of samples during sampling process, despite the care taken to avoid such contamination
- contamination of piezometer water by entering of herbicide spray or contaminated dust into the piezometer through a small diameter hole in the piezometer cap.
- contamination of the piezometer completion zone by contaminated augerflight samples which may have fallen into the hole during augering or just prior to installation of the piezometer
- contamination introduced in piezometer water during water level measurements.

- analytical error, despite efforts to eliminate such errors by analyzing blank and spiked samples prior to and after analysis of batches of groundwater and surface water samples.

Since most of the potential causes of contamination described above are of an external nature, it can be concluded that the results of the 1987 study indicate that there is no clear evidence that herbicides occur in the shallow groundwater at the three sites and if they do occur it is at concentrations of less than 1 ppb.

In summary, the data obtained in 1987 are inconclusive as to the origin of the detected herbicides in water from the piezometers.

As with hazardous waste sites, extreme care during piezometer installation and collection of water samples is essential, in particular when expecting very low levels of contaminants. To eliminate many of the ambiguities related to piezometer installations, the following measures would have to be taken: steam-clean or wash augers, drillstems or coring equipment,install pre-cleaned stainless steel screens and casing, pre-wash gravel pack material. Such measures are probably more needed when installing piezometers in fine-texture materials since piezometers completed in sand can be cleaned-up by extensive pumping prior to sampling.

Uncertainties with regard to reliability of analytical results can be reduced by taking duplicate samples and trip-blanks, and by submitting samples to different laboratories.

For future studies, the Pederson site is the most suitable of the three sites investigated in 1987 since the site is well known and represents the worst case scenario because of the gravity irrigation. Furthermore, it allows a more detailed study of the fate of the herbicides applied on the land because of the surface water studies. Future studies at this site require selection of sites within the study area for installation of piezometers completed at different depths, detailed soil moisture measurements and detailed soil sampling and analysis.

The SIDC site is less suitable for further study because of the complexities related to land use, herbicide use and application of irrigation.

The Konst site offers potential for further investigations since he near surface geology is significantly different from that at the Pederson and SIDC sites. Further research could focus on the downward migration of herbicides beneath a field irrigated with a central pivot system. In addition, investigation of possible contamination of the shallow groundwater as result of canal leakage is a potential research subject.

9. ACKNOWLEDGEMENTS

Messrs R. Pederson and J, Konst are gratefully acknowledged for allowing access to their land and for their support and interest in the project.

Mr. L. Tollefson, Manager, Saskatchewan Irrigation Development Centre, is thanked for allowing the construction of ten piezometers at the SIDC site and for providing data on herbicide use and on amounts of irrigation applied in 1987.

Mr. C. Rogal, Saskatchewan Water Corporation, West Central Region, is acknowledged for providing data on the piezometer installations at the Konst site and for his useful discussions on the hydrogeology of the site. He also measured the water levels in Pederson piezometers from October 1987 to April 1988.

Mr. D. McNaughton, National Hydrology Research Institute, Groundwater Division, is acknowledged for preparing the joint Pestfund proposal and for reviewing a draft of this report.

Mr. L.A. Kerr, Agriculture Canada, Regina Research Station, carried out the herbicide analyses.

The Prairie Farm Rehabilitation Administration is gratefully acknowledged for making their cable tool rig available to drill the piezometer holes at the SIDC site. Drilling at the Pederson site was done by McRae Augering Ltd., Conquest.

The EM-31 survey was carried out by Messrs. K. Best and R. McKay, National Hydrology Research Institute, Surface Water Division and by Mr. D.A. Zlipko, Saskatchewan Research Council, Sedimentary Resources.

The project was funded by the Pestfund, Environment Canada, and by the National Hydrology Research Institute and the Saskatchewan Research Council.

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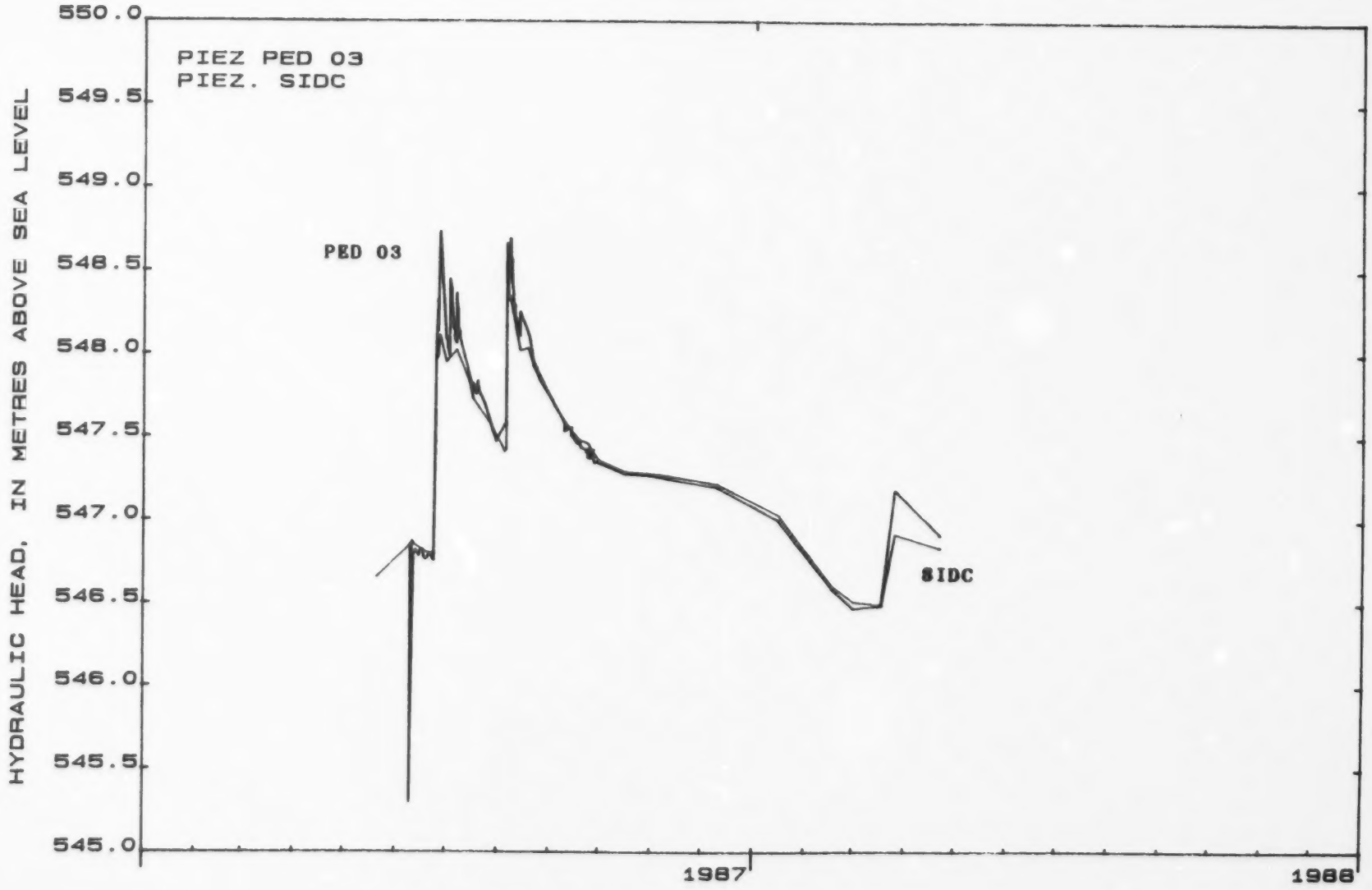
APPENDIX A

Hydrographs for Pederson piezometers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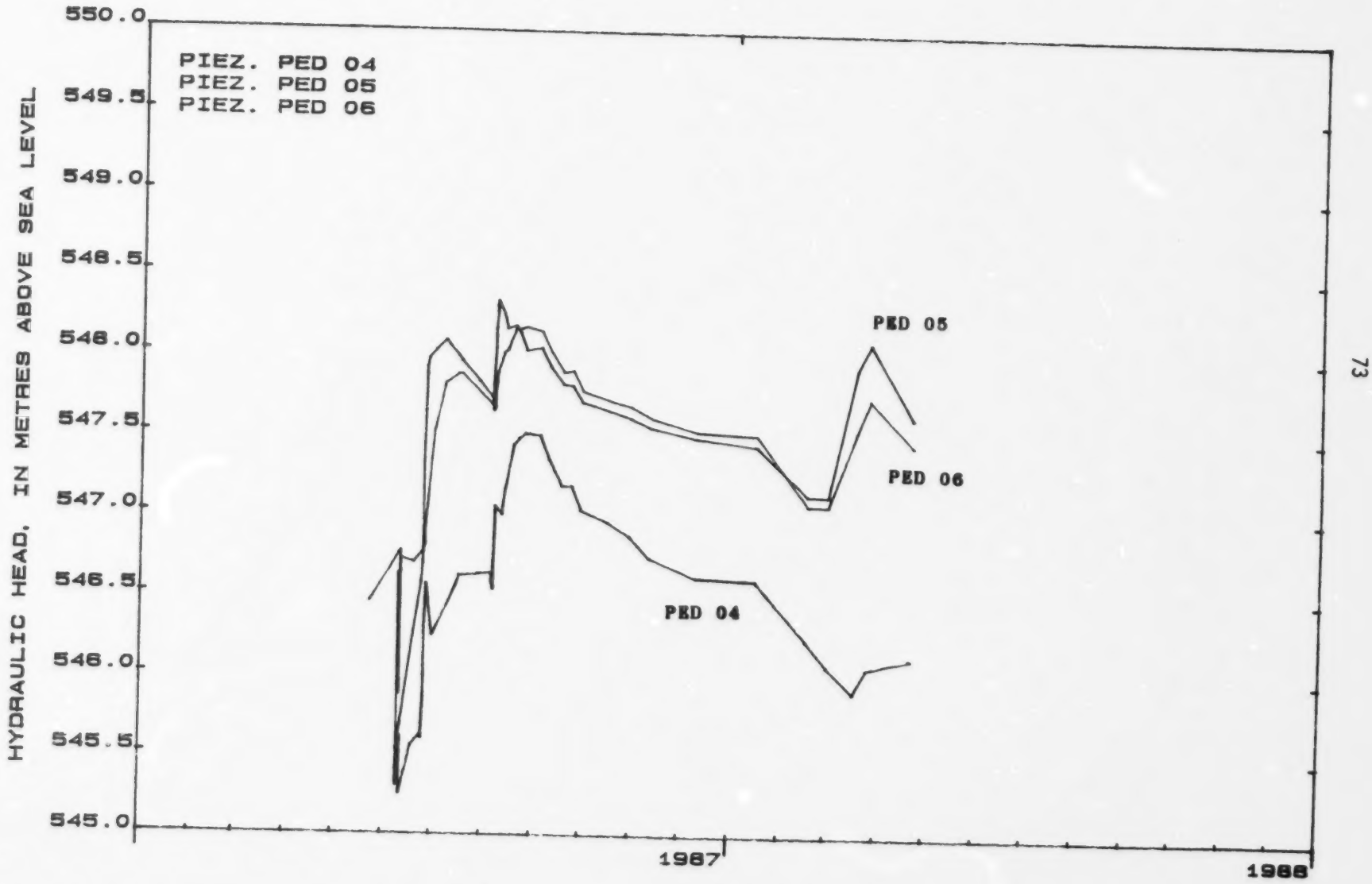
1988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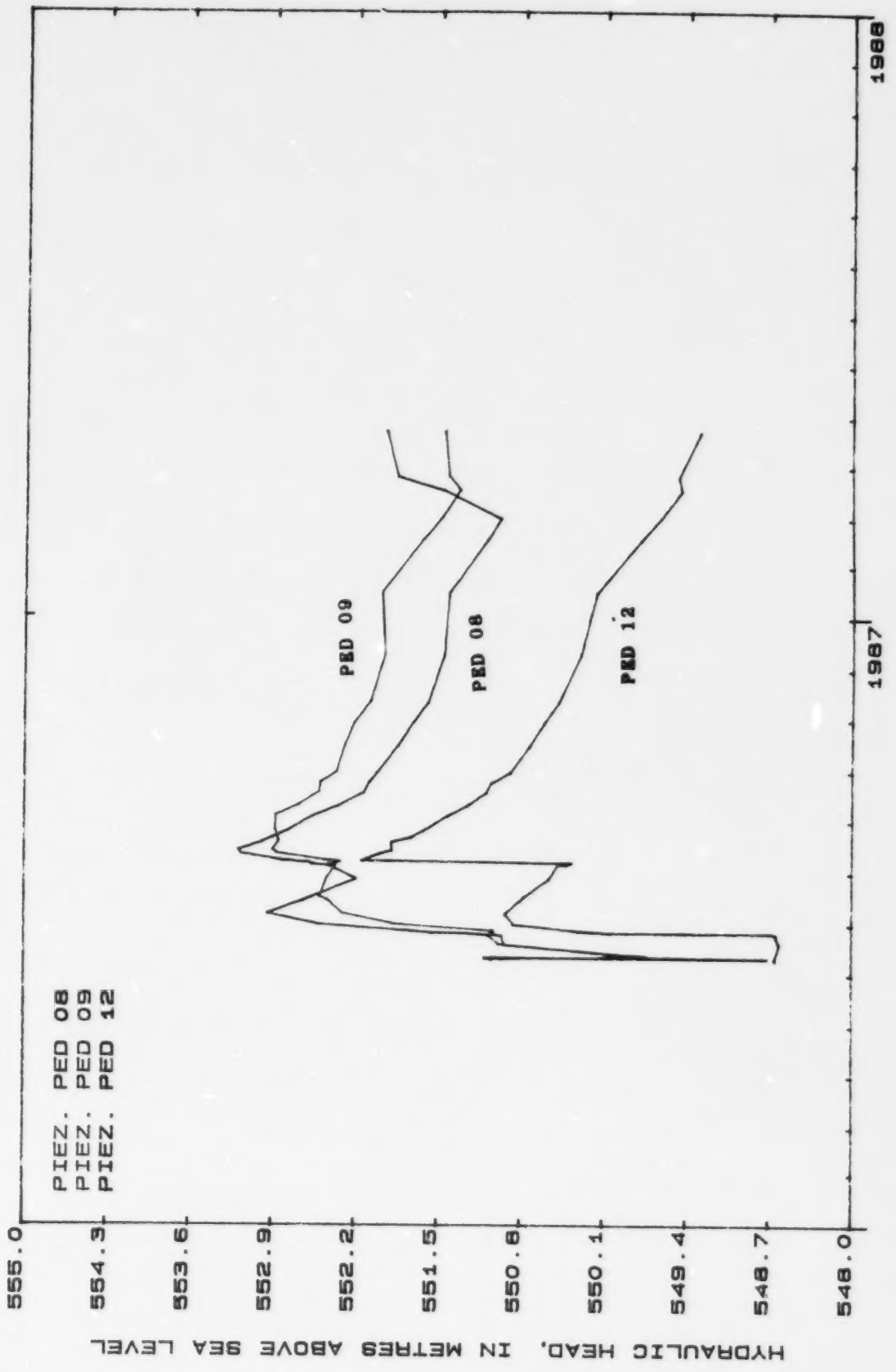
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1988
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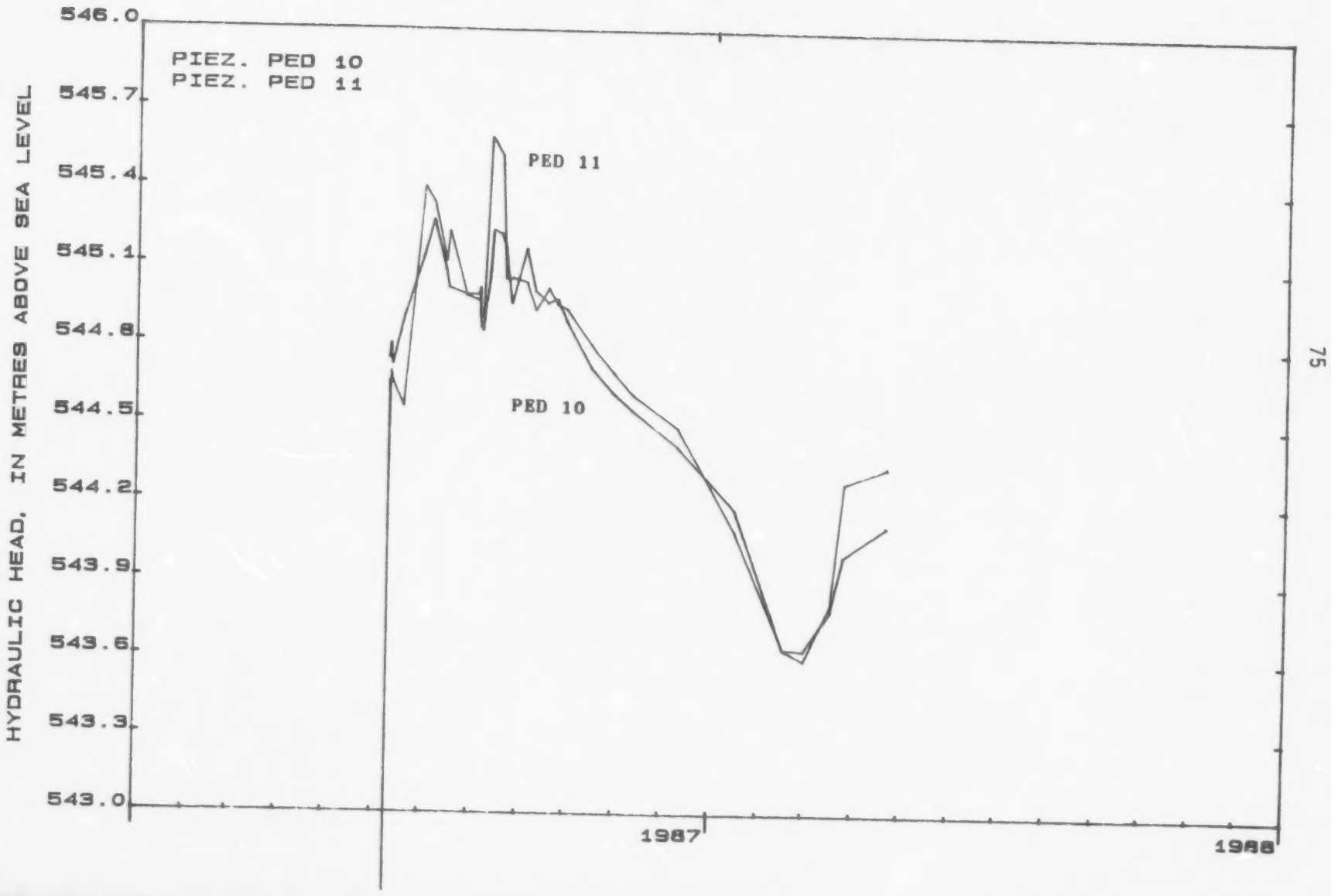
PIEZ. PED 09
PIEZ. PED 12
PED 09
PED 08
PED 12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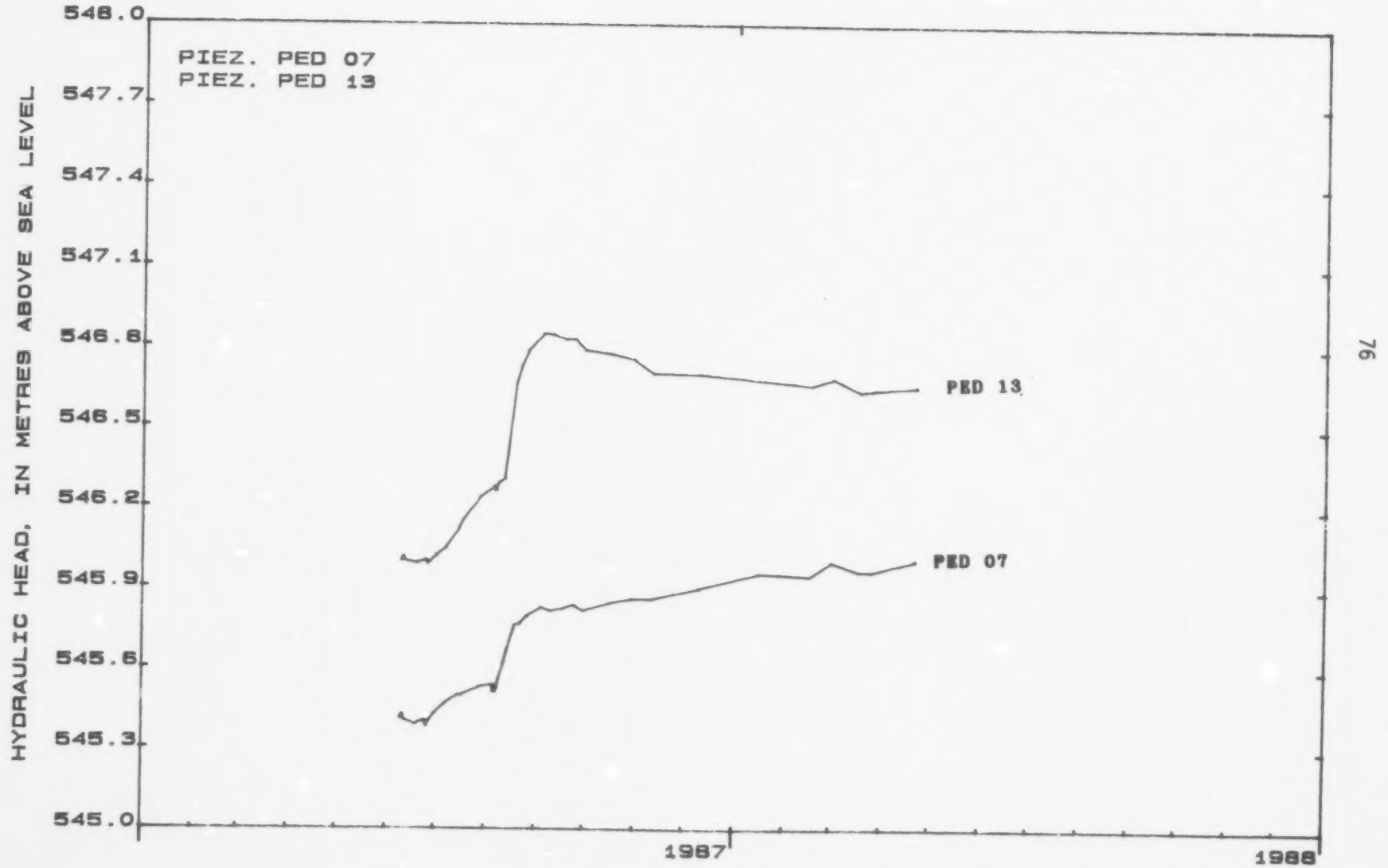
PED 10
1987
1988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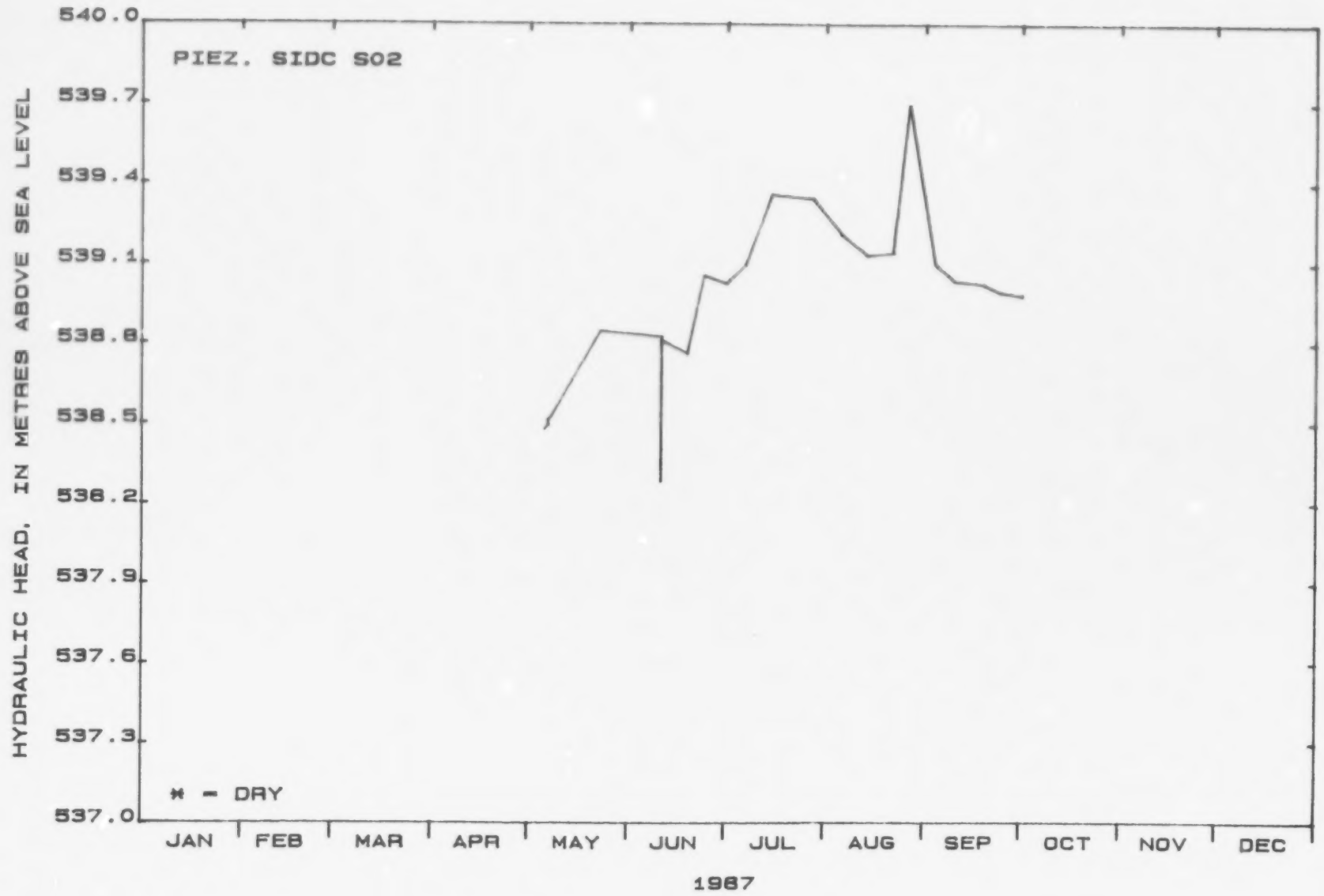
APPENDIX B

Hydrographs for SIDC Piezometers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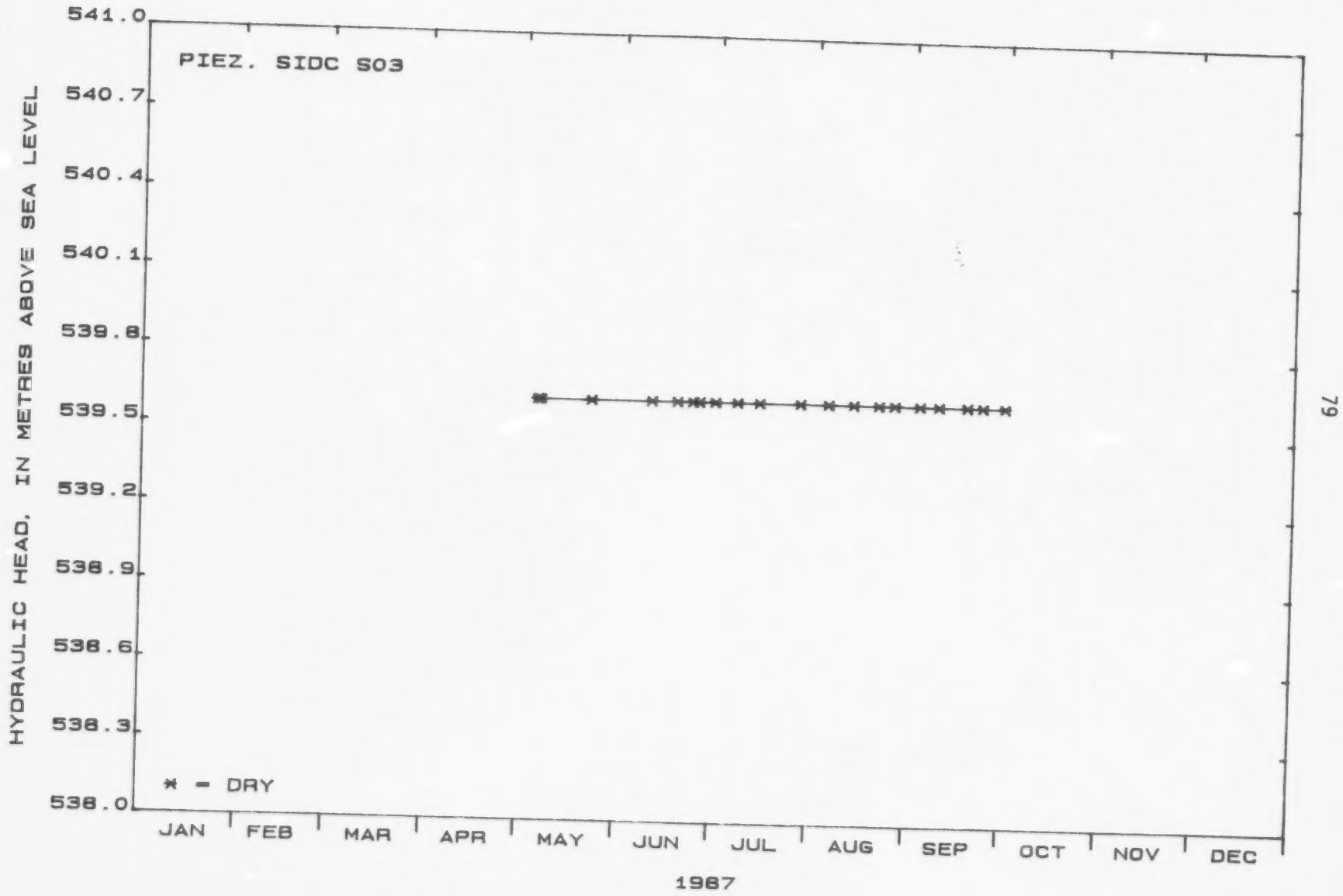
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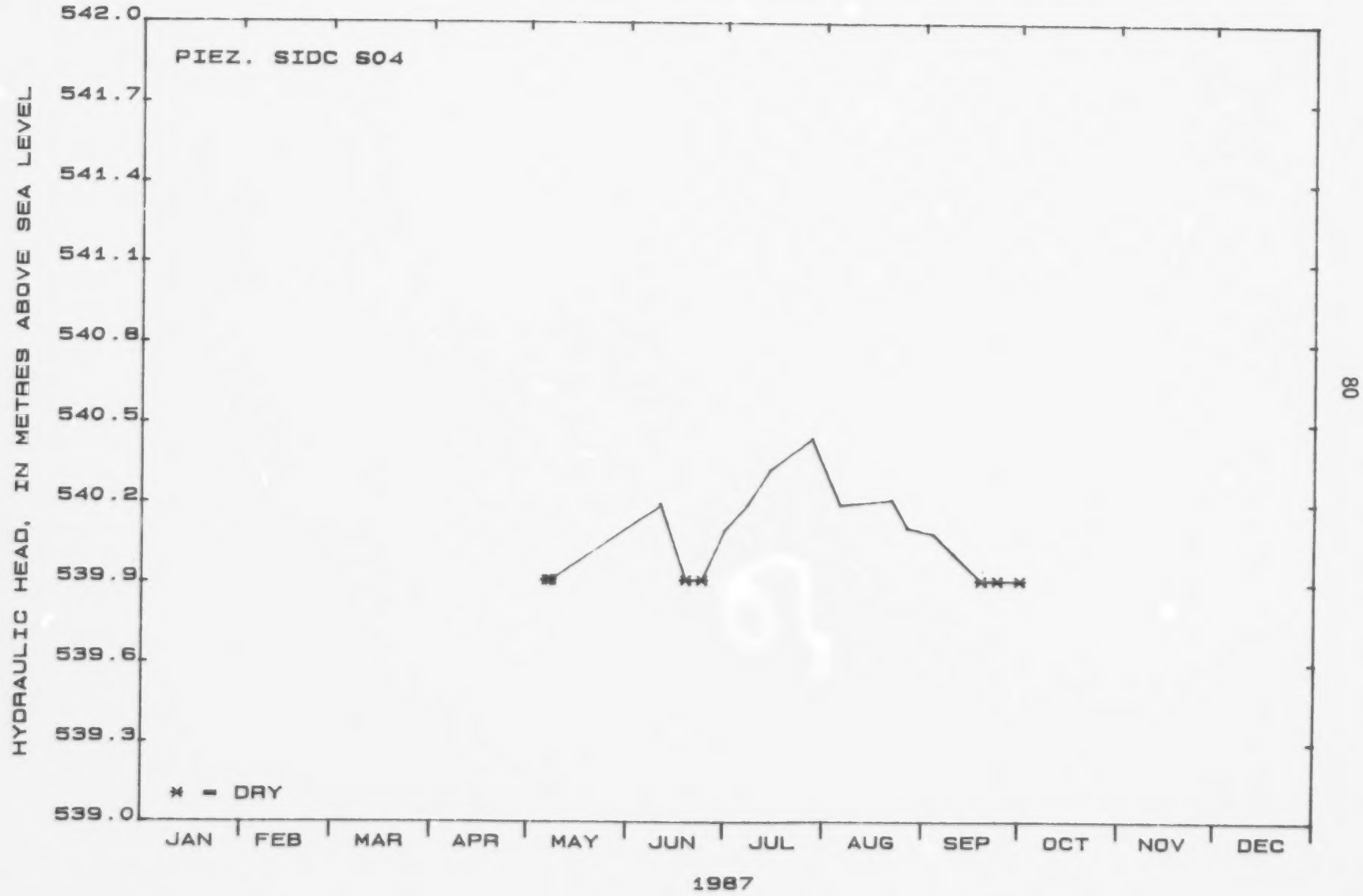
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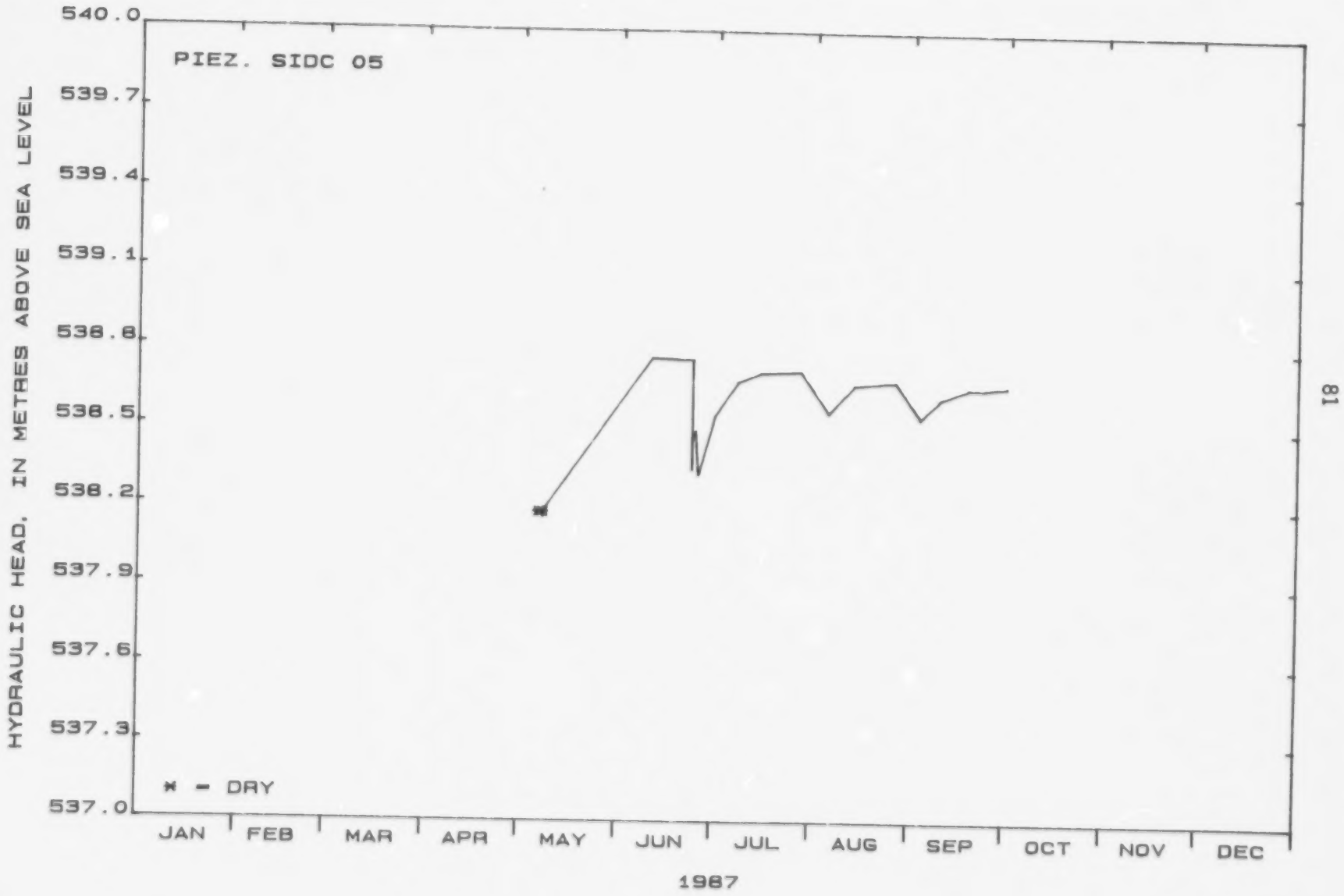
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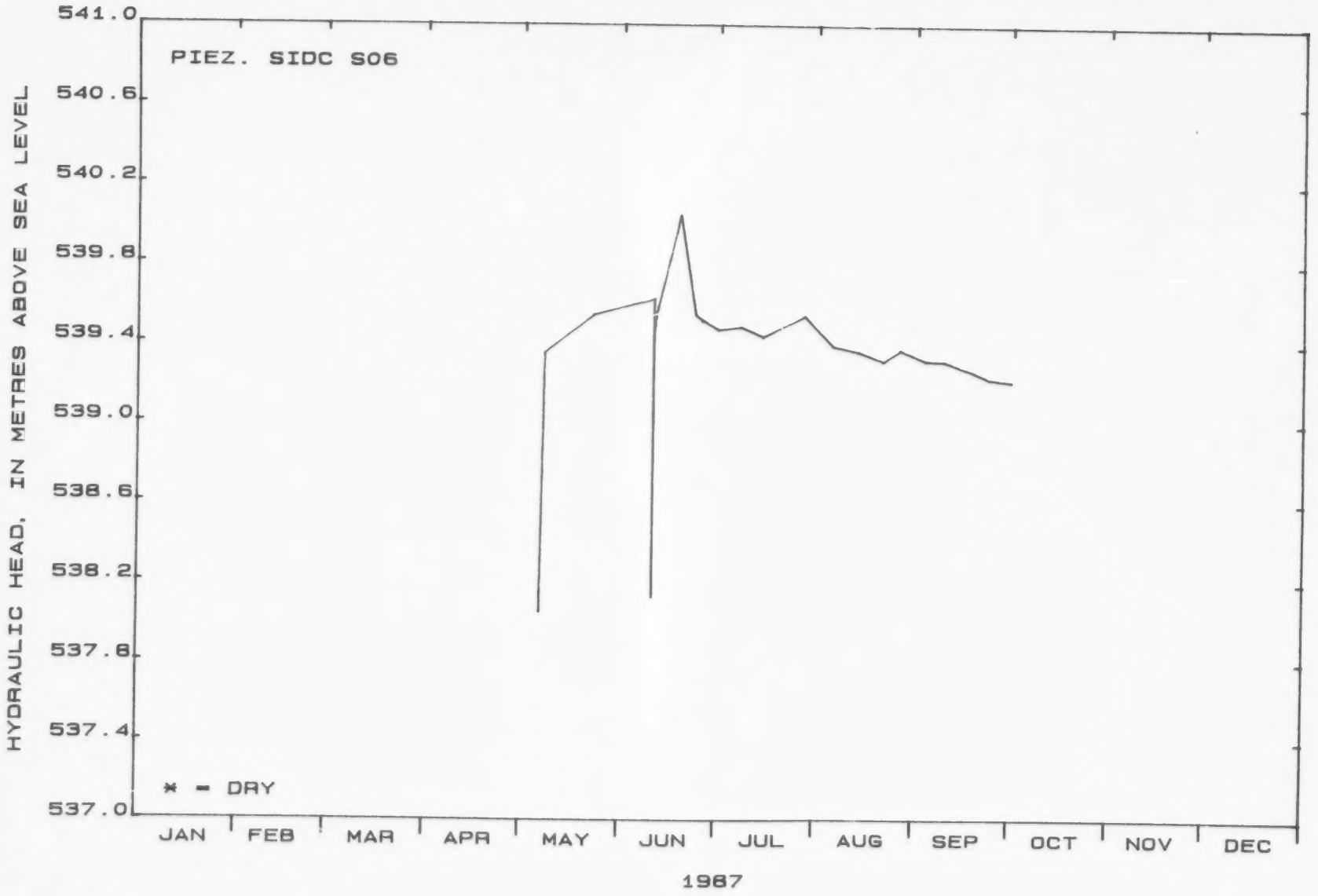
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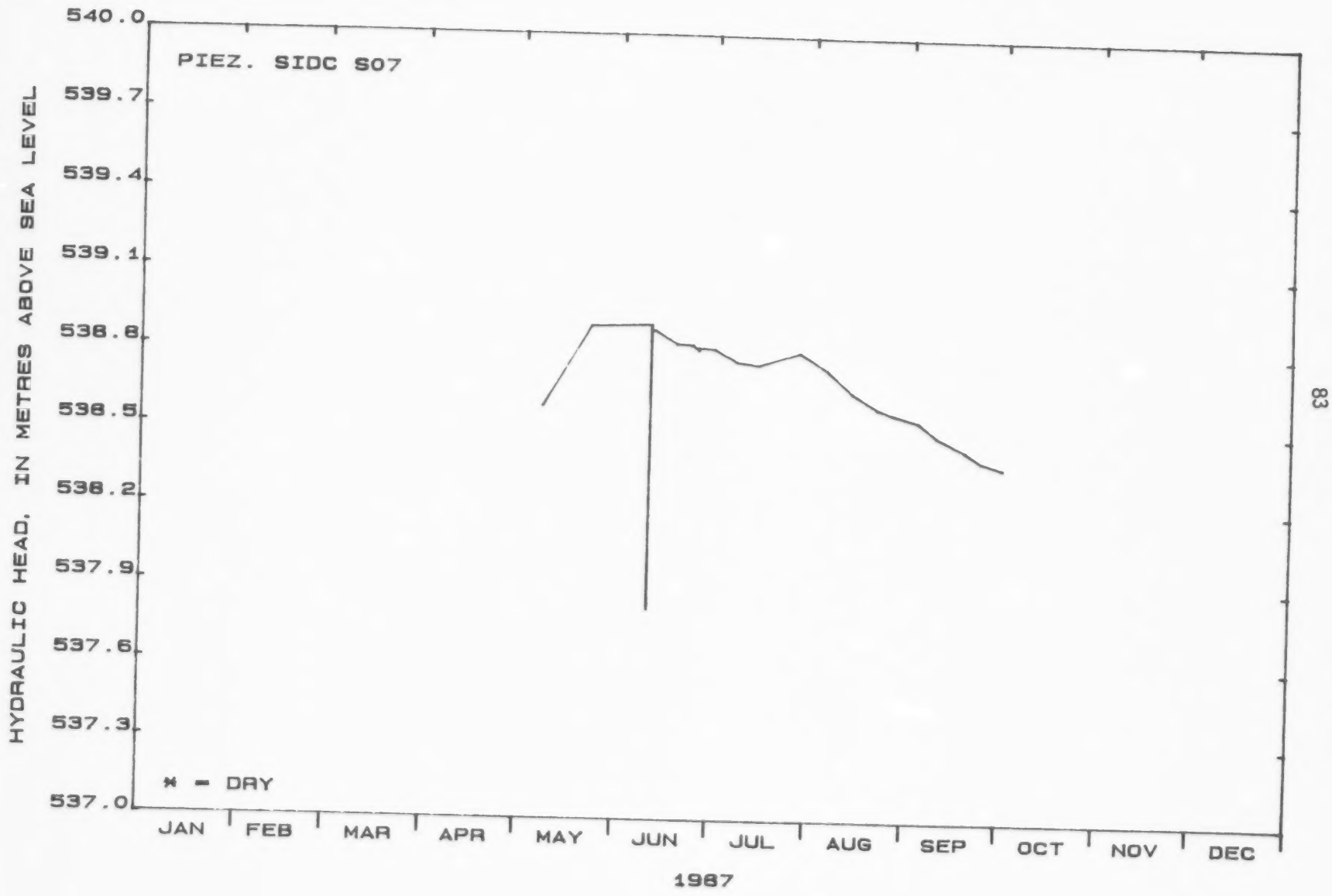
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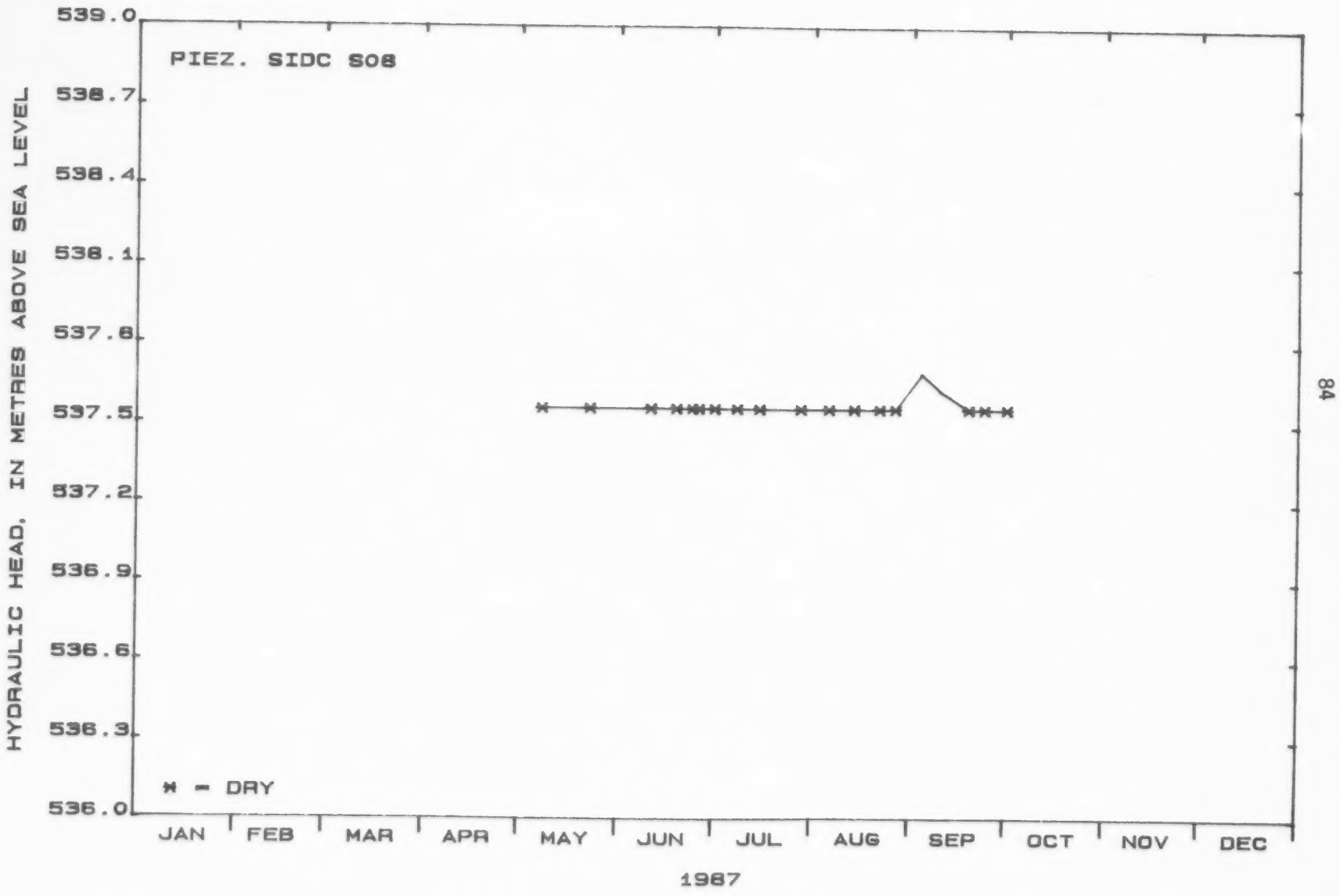
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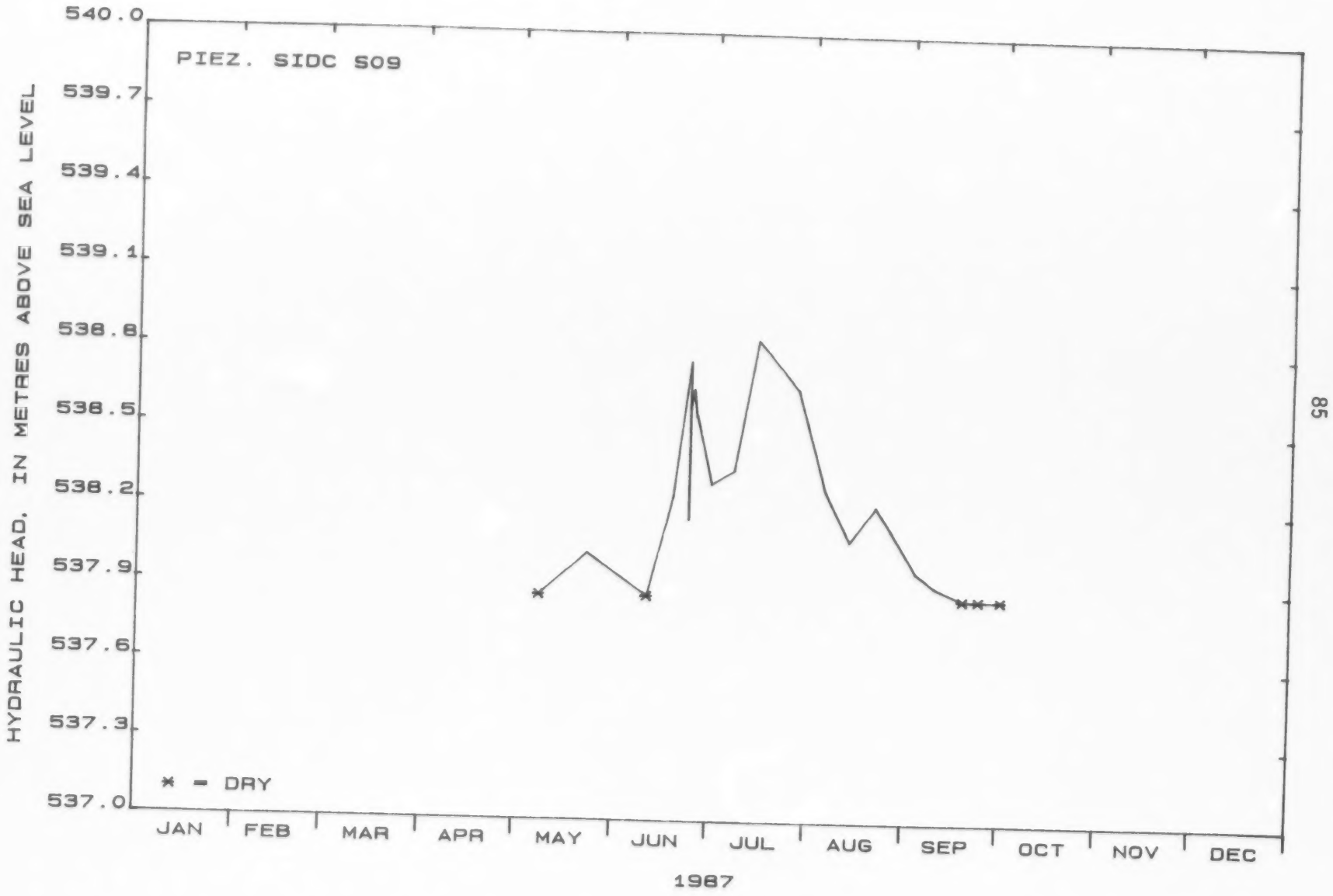
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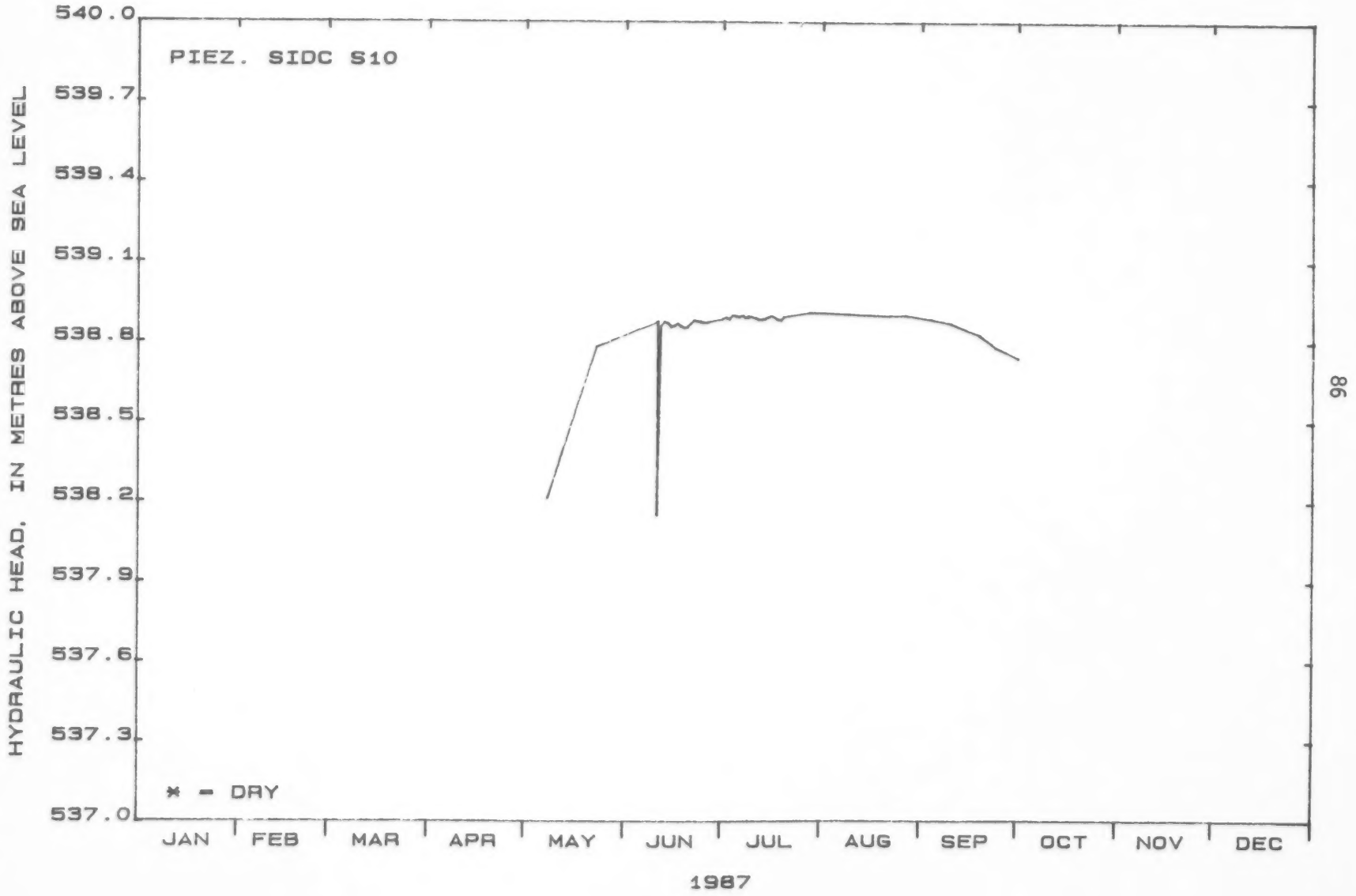
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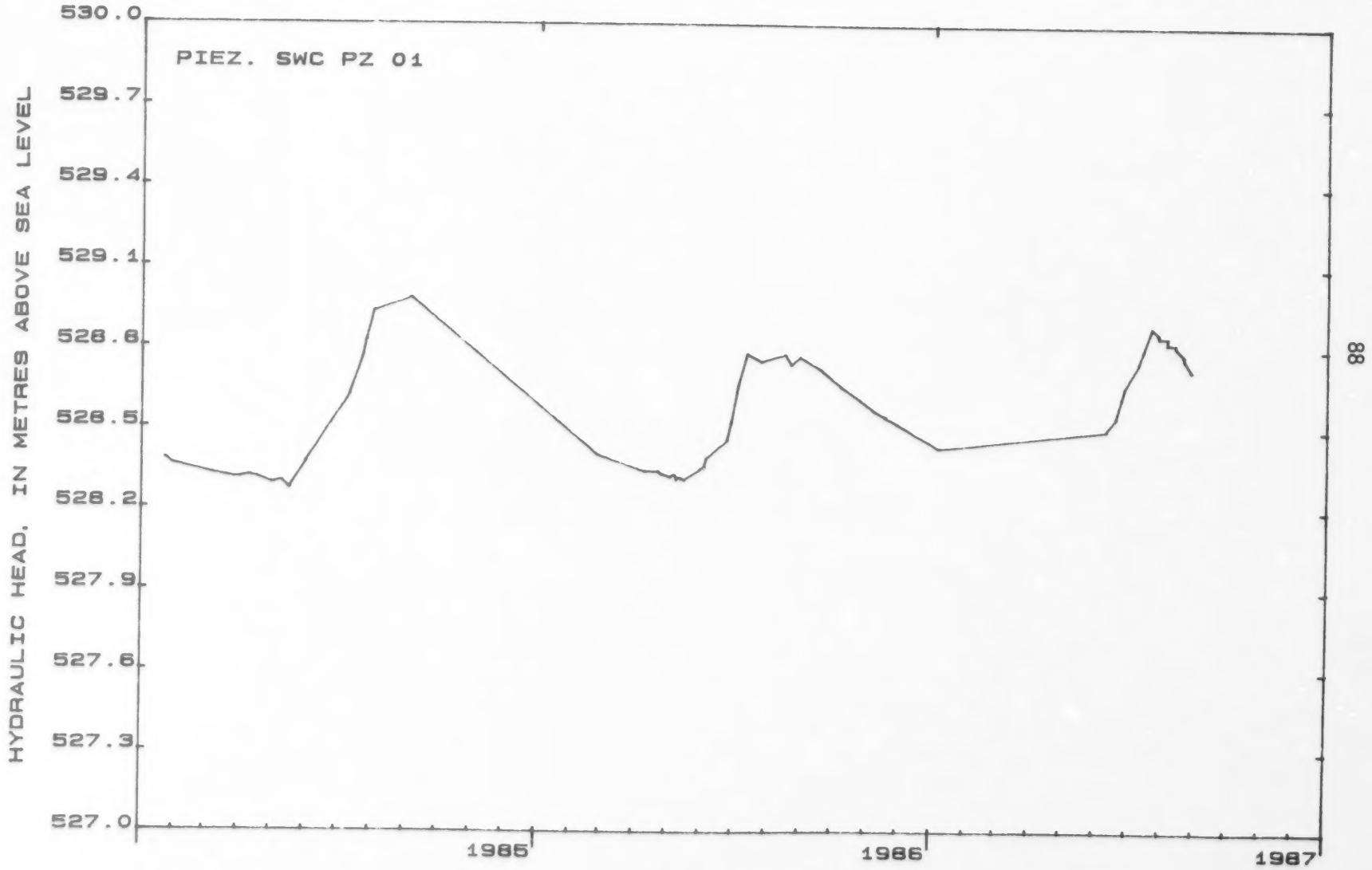
APPENDIX C

Hydrographs for selected piezometers at Konst site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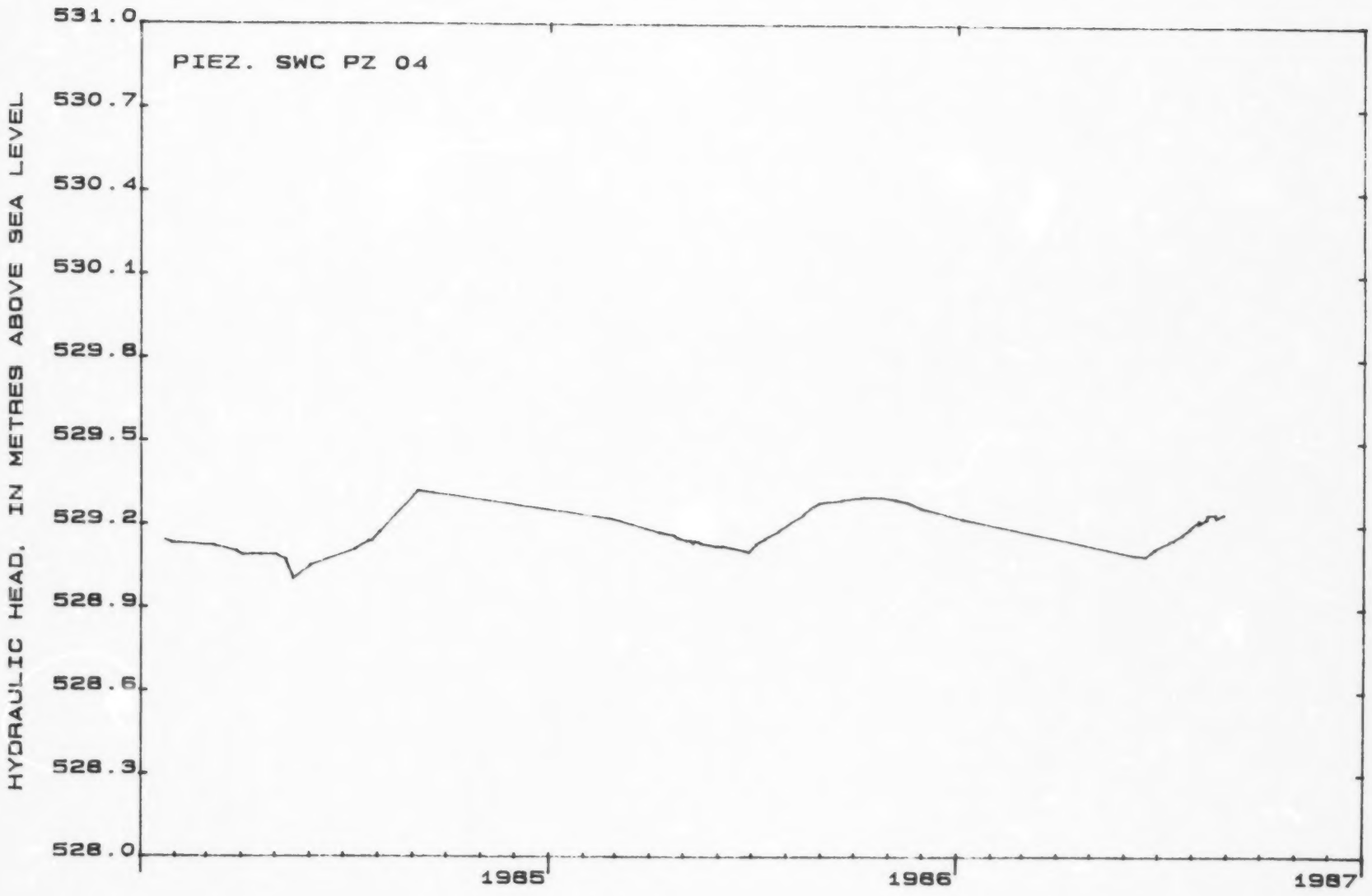
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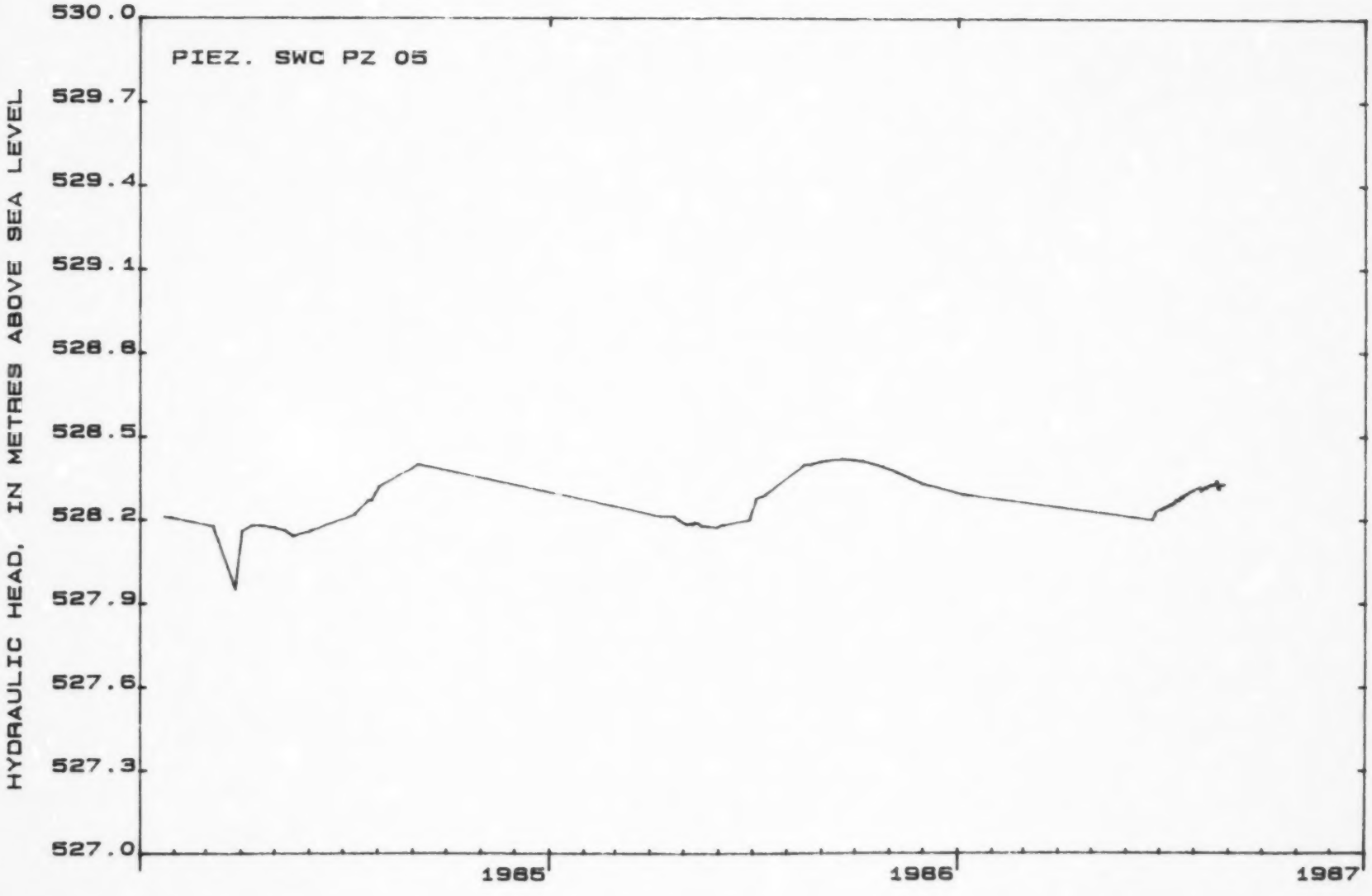
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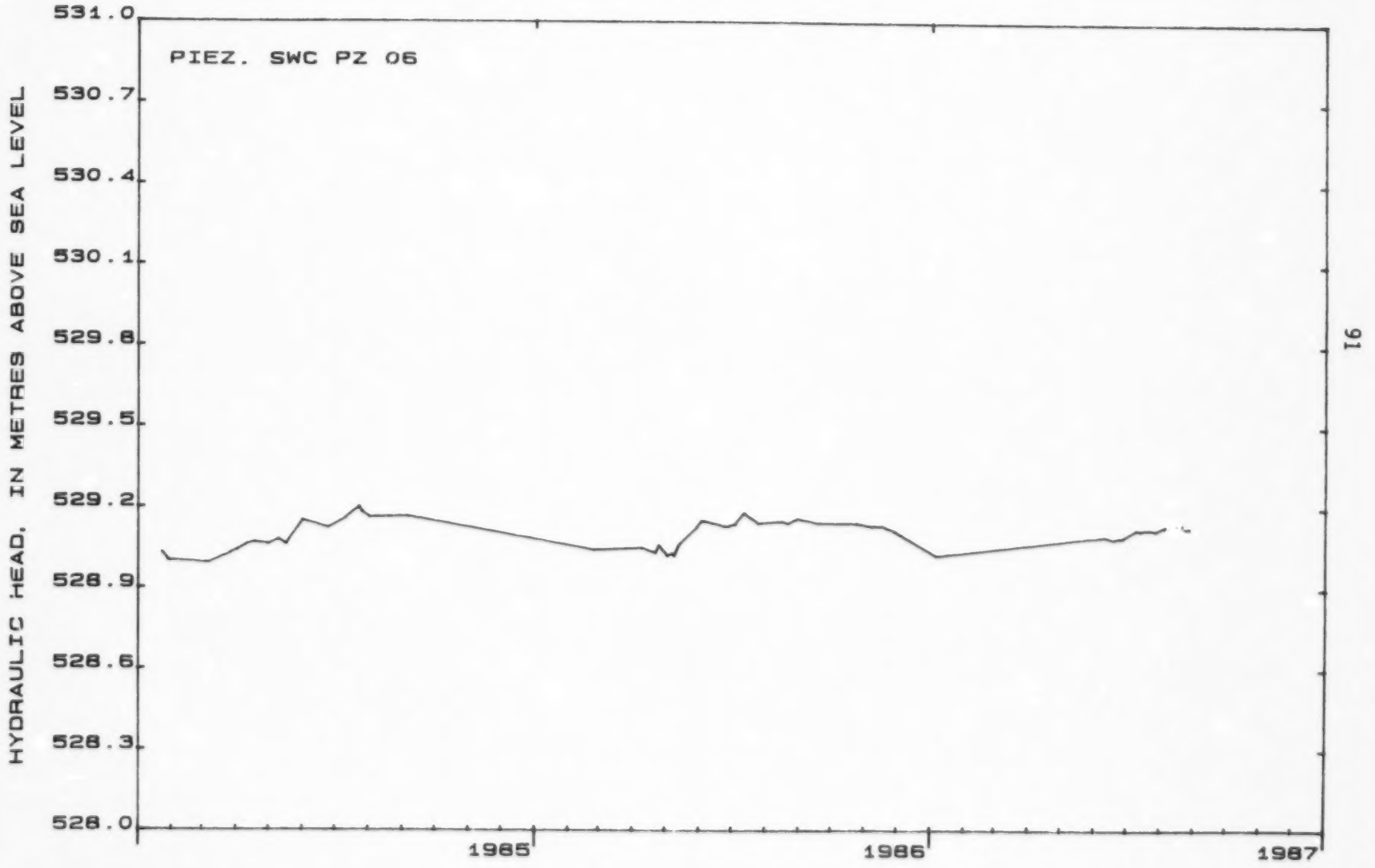
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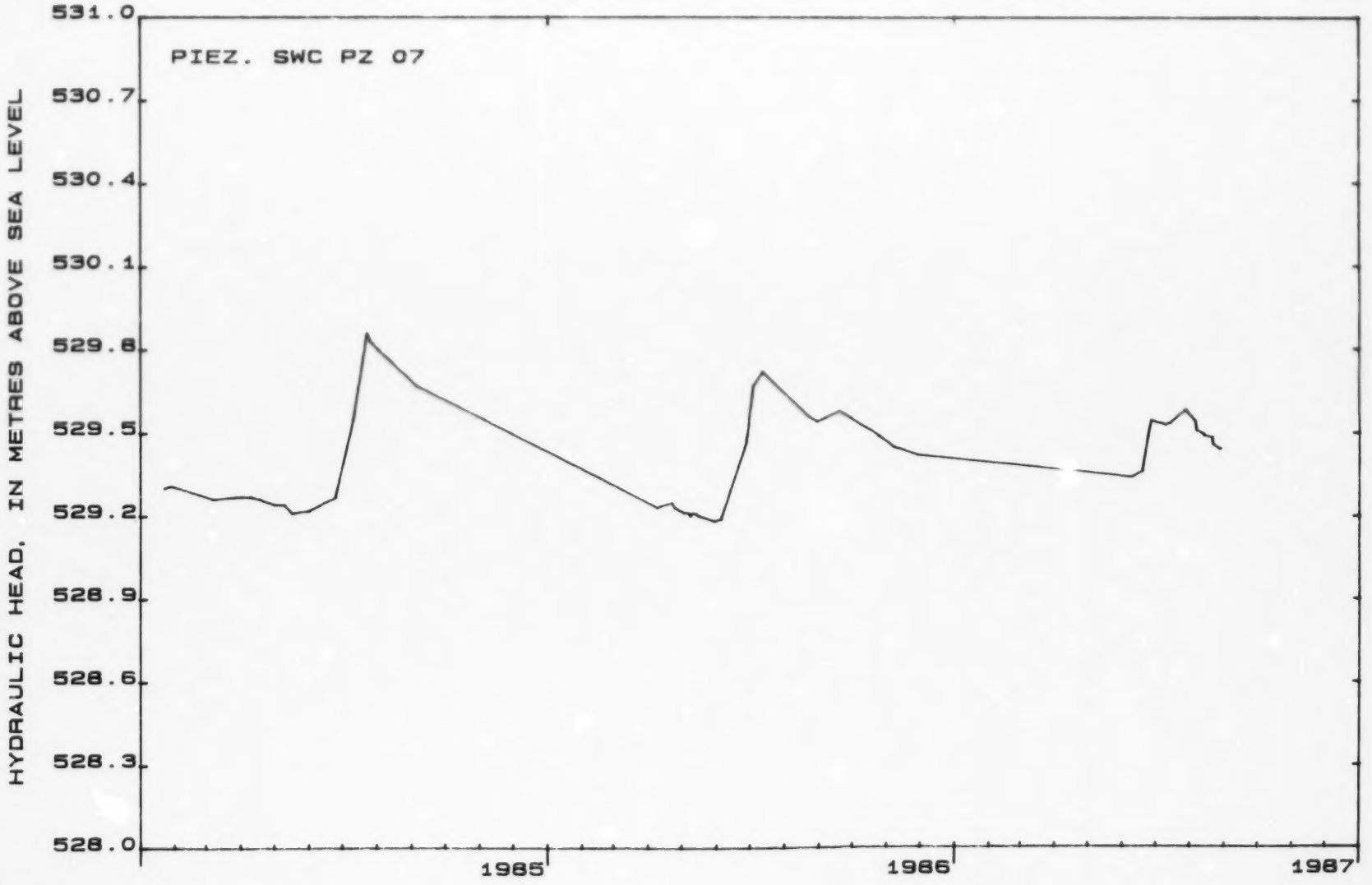
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1986
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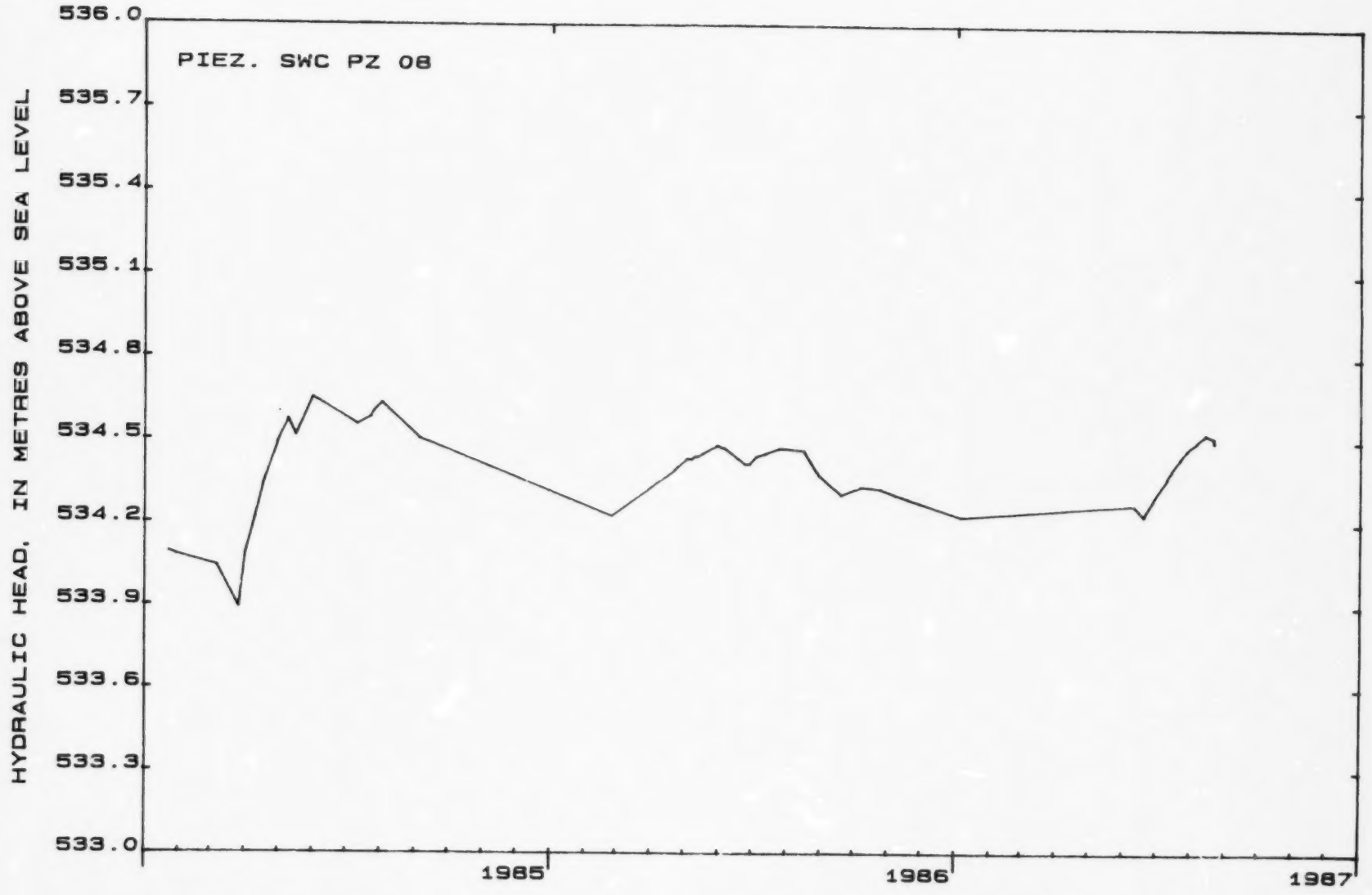
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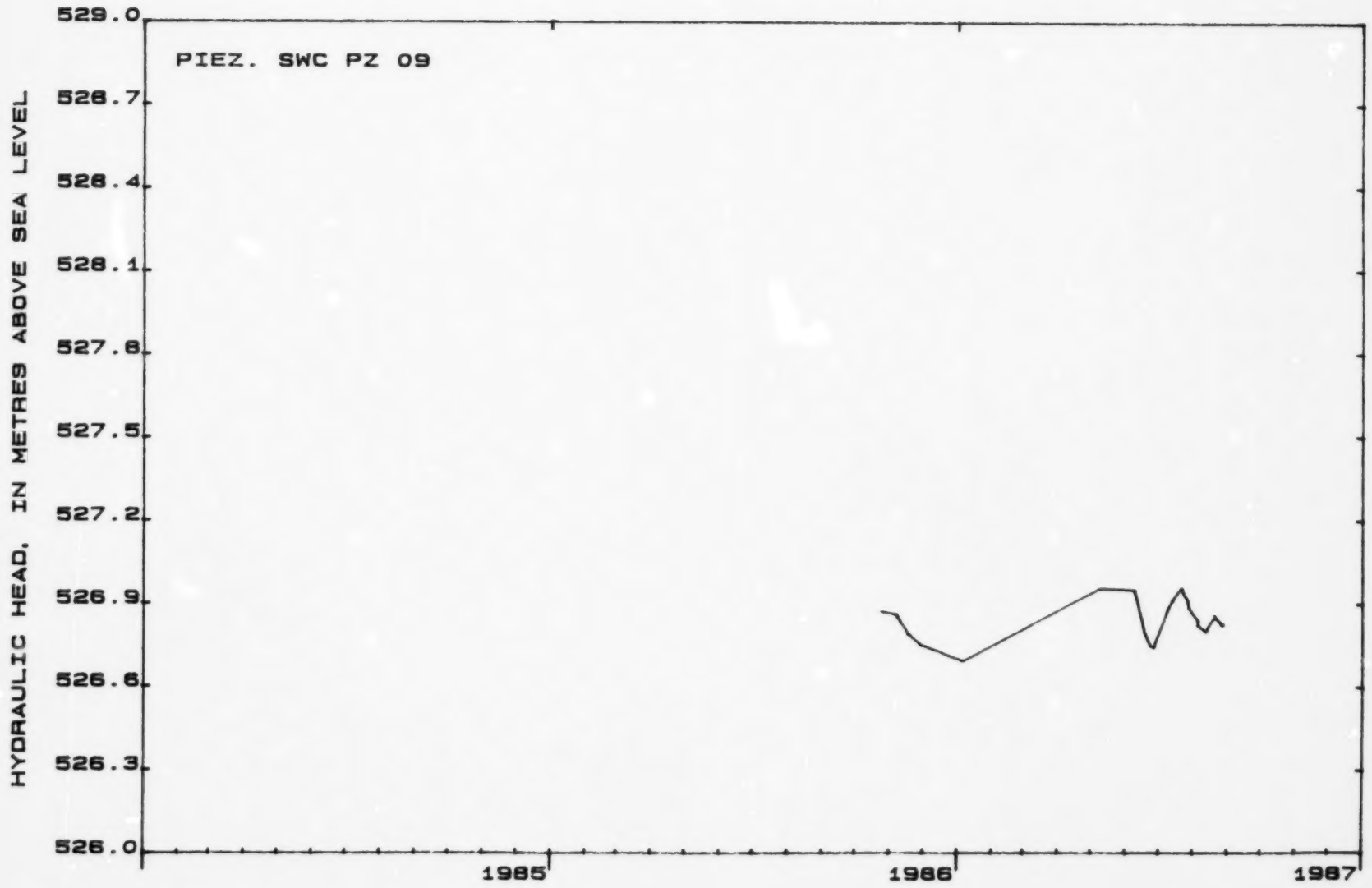
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528.1
527.8
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1985
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